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BUILDING CONSTRUCTION

AND SUPERINTENDENCE.

BY

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REVISED AND ENLARGED

BY

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Part I.

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PREFACE TO FIRST EDITION.

THE primary object of the author in preparing this volume has been to present to the student, architect and builder a text-book and guide to the materials used in architectural masonry and the most approved methods of doing the various kinds of work, and incidentally to point out some of the ways in which such work should not be done, and the too frequent methods of slighting the work. That there is a demand for such a work has been evidenced to the author by numerous inquiries from architects and instructors in our architectural schools, and also by the fact that there exists no similar work describing American methods and materials.

In describing methods of construction the author has drawn largely from his own observation and experience as a practising and consulting architect, in both the Eastern and Western States, although much assistance has been obtained from prominent architects, who have cheerfully aided him by their advice and experience, and from the various books and publications to which references are made in the text; to all such the author gratefully acknowledges his indebtedness.

To make the book convenient for practical use and ready reference, the various subjects have been paragraphed and numbered in bold-face type, and numerous cross references are made throughout the book. The table of contents shows the general scope of the book, the running title assisting in finding the various parts, and a very full index makes everything in the book easy of access. The general character of the work is descriptive, and hence rules and formulæ for strength and stability have, except in a few cases, been omitted; such data being already fully presented in the author's "Pocket-Book" and other similar works.

While intended principally as a book of instruction, there is much in the book that will be found valuable for reference, and of assistance in designing and laying out masonwork, preparing the specifications, and in superintending the construction of the building, so that the author hopes that even the experienced architect will find it of assistance in his work.

The enterprising builder, also, who wishes to thoroughly understand the materials with which he has to deal, and the way in which they should be used, will find in this book much information that cannot be readily obtained elsewhere.

To make the description as clear as possible many illustrations (mostly from original drawings) have been inserted, and an endeavor has been made to present only practical methods, and to favor only such materials as have been found suitable for the purpose for which they are recommended.

F. E. KIDDER.

Denver, Colo., June 1, 1896.

PREFACE TO REVISED EDITION.

IN offering this new edition of "Building Construction and Superintendence, Part I, Masons' Work," to the public, the author of the revision has constantly borne in mind the original purpose of the book as set forth by Mr. Kidder in the preface to the first edition. He has endeavored to bring it down to the present day in such form that it will continue to hold a high place as one of the standards of the best contemporary practice in the elements of architectural masonry construction and superintendence. While he has endeavored to explain the principles of the subject in a way that may be readily understood and followed by all who are in any way connected with or interested in building operations, whether architects, engineers, contractors, students, artisans or the general public, he has, at the same time, tried to set forth these principles and methods of procedure in a scientific manner, preserving and further strengthening the purpose of the work, not only as a hand-book for professional and commercial use and reference, but also as a text-book for schools and colleges. He must leave it to those who use the revised work to decide the measure of his success.

It was Mr. Kidder's intention to publish a thoroughly revised edition, and shortly before his death he expressed the wish that the writer undertake the work. The labor put upon it has been lightened by the memories of a friendship lasting through many years.

The work has been congenial, those divisions of the theory and practice of architecture which include building construction and superintendence having been the subjects of special study on the part of the writer for many years. It embodies notes made and conclusions arrived at in the design, construction and superintendence of different types of buildings during a practice of many years and includes also notes made in special study and research in connection with courses of lectures given in the School of Architecture of the University of Pennsylvania on the theory of and practical procedure in architectural construction. Much time, labor and thought have been required for the preparation of the revision and it is hoped that the usefulness of the book will be greatly increased.

Four years ago, in writing the preface to a late edition of another of his works and in comparing that edition with the preceding one, Mr. Kidder said: "At that time the author thought he had covered all those practical details relating to the planning and construction of buildings, with which the architect was concerned, tolerably well, and it would appear as though the publishers of the book thought so, too; but as the years have come and gone, so many and such great improvements have taken place in the building world, so many articles invented, new methods of construction developed, and higher standards established, that the present edition is perhaps not more complete for the times than was the first edition."

This may be said of the present edition as related to the preceding edition of "Building Construction and Superintendence, Masons' Work."

The new edition includes, in general, a careful examination of every article in the book and a revision of every one in which changes, omissions or additions of data or methods of procedure are deemed necessary or advisable; the omission of some articles and the addition of many new ones; the rewriting of some chapters and the addition of one entirely new chapter; the addition of nearly four hundred new illustrative constructive drawings; the addition of many new tables and formulas; the classification of the subdivisions of each chapter; the addition of titles to every article and illustration; the addition of new footnotes referring to many authorities for further data; and a new and comprehensive index with very numerous cross references.

In Chapter II, "Foundations on Compressible Soils," the subject of "Caisson Foundation Construction" has new examples taken from recent noted buildings, and the general principles of "Heavy Cantilever Foundation Construction" are explained and illustrated.

Chapter III, "Masonry Footings and Foundation Walls, Shoring and Underpinning," has, among other additions, new articles relating to "Recent Examples of Heavy Needling and Underpinning."

Chapter IV, "Limes, Cements and Mortars," is rearranged, enlarged and entirely rewritten. The subdivision dealing with concretes is taken out and treated in Chapter X, "Concrete and Reinforced Concrete Construction." The great and ever-increasing importance of the subject matter of this part of the subject, and the vast amount of new and useful data resulting from recent experiments and tests, led the writer to widen largely the scope of this chapter.

Chapter V, "Building Stones," is virtually rewritten. There are seven new tables. The revision includes much new matter relating to the "Production and Value of Different Kinds of Building Stones," the "Distribution of Building Stones in the United States," the "Minerals of Building Stones" and the "Classification of Rocks Used for Construction Purposes," and additional lists, containing a very large number of examples of new buildings in which the different kinds of stone have been used, are added.

Chapter VII, "Bricks and Brickwork," is carefully revised in accordance with much new data. Included in the new matter of the text and illustrations may be mentioned especially "Sand-lime Bricks," "Surface Patterns in Brickwork" and "Brick-veneer Construction."

Chapter VIII, "Architectural Terra-cotta," is entirely rewritten, enlarged and illustrated with many new figures. Special attention is given to the subjects of "Composition and Manufacture," "Surface Treatment" and "Polychrome Terra-cotta;" and there are numerous examples of architectural construction taken from recent prominent buildings.

Chapter IX, "Fire-proofing of Buildings," is entirely rewritten, very much enlarged and illustrated with two hundred figures.

Chapter X, "Concrete and Reinforced Concrete Construction," is a new chapter with over one hundred illustrative drawings. The marked increase in the use of concrete in all kinds of buildings and the rapid development

of reinforced concrete construction make the subject matter of this chapter of great relative importance, and it is treated as fully as the limits of the book permit. The third division deals with "Reinforced Concrete Construction." The subdivision, "General Theory and Design," includes a brief outline of the principles of the mechanics of materials leading to the theory of flexure of reinforced concrete beams, girders and slabs and to the theory of reinforced concrete columns, and is purposely made to agree with the general presentation of the subject in the revised chapters of Mr. Kidder's hand-books, so that these books may be conveniently used together. Useful working formulas and tables are introduced in conformity with Mr. Kidder's custom as exemplified in the several chapters of preceding editions of this work. The fourth division of the chapter deals with "Concrete Block Construction" and includes a discussion of the different types of blocks, the composition of the materials used, the processes of manufacture and the details of building construction.

In Chapter XII, "Lathing and Plastering," the matter dealing with "Hard Wall Plasters" is rewritten, and made to conform as closely as possible to the facts and to the conditions prevailing at the present time.

Chapter XIII, "Specifications," is revised and enlarged with many new pages of text. Several new specifications have been inserted, for cements, concrete blocks, etc., and complete specifications for the reinforced concrete work of a recently erected building are added.

The Appendix is rearranged and greatly enlarged by the addition of many tables. Addendas of recent valuable data relating to the "Weight, Crushing Strength and Ratio of Absorption of Building Stones" and of "Lists of Recently Erected Stone Buildings" are inserted and tables giving recent data concerning the "Building Stone Industry in the Different States" and giving the "Comparative Characteristics of the Different Slates" are added. Ten new tables containing data relating to cements are added, dealing with the "Geographical Distribution of Cements," the "Production of Cements," the "Development of the Cement Industry," the "Imports and Exports of Cements," the "Total Consumption of Cements," etc. New tables relating to clay products used in building operations are added, giving the "Products of Clay in the United States" during the past decade and the "Value of Clay Products." Tables are added, also, showing the extent of "Building Operations in the United States" and the "Character of the Buildings Erected."

Throughout the entire revision the writer has taken great pains to furnish reliable data. Wherever possible, references to the sources of information are given, either in the text or in the footnotes. To all who have assisted him in any way the writer acknowledges his indebtedness, and expresses his thanks.

The names and addresses of manufacturers and dealers in materials and appliances used in masonry construction are given when necessary, and any possible advertising resulting from the insertion of any name is entirely accidental and incidental to the purposes of the book.

The author of the revision requests that readers will kindly call his atten-

tion to any typographical or other errors, in order that they may be corrected before the next edition goes to press.

He desires to acknowledge his indebtedness to Mrs. F. E. Kidder for many valuable suggestions relating to the revision, and to the publisher who has done everything possible to coöperate in the efforts made to increase the usefulness of the work.

THOMAS NOLAN.

Philadelphia, Pa.
February, 1909.

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INTRODUCTION.

THE successful practice of architecture requires not only ability to draw and design, but also a thorough knowledge of building construction in all its branches; at least in so far as to know *how* the work should be done, and for conscientious and painstaking supervision of the work.

Without a knowledge of the best methods of performing building operations, and of the materials that should be used, it is impossible for the architect to prepare his specifications intelligently, and so as to secure the kind of work he wishes done. Upon the thoroughness with which the specifications are prepared depends in a great measure the satisfactory execution of the work.

The position occupied by the architect as a judge or referee between the owner and contractor also makes it necessary that he should be able to show such thorough familiarity with common practice as will command the respect of both. Workmen soon discover whether the superintendent is familiar with the difference between good and bad work, and if they find him wanting they are quite sure to take advantage of his lack of knowledge.

After the plans and specifications have been prepared with the utmost care, accidents, failures and bad work are quite sure to occur unless the building operations are carefully and intelligently supervised. In fact, probably more failures in buildings occur from the use of poor materials and bad workmanship than from faults in the plans.

While it is impossible for one to acquire a thorough knowledge of building construction from books alone, it is necessary, for the young architect especially, to depend upon technical books to a large extent for his knowledge of how work should be done, and of what materials are best suited for certain purposes, and how they should be used. As a substitute for his lack of knowledge, he must rely largely upon knowledge gained through the experience of others, oftentimes at great cost.

In these books the author has endeavored to describe all the ordinary building operations in such a way that they may be easily understood, to point out the defects often met with in building materials and construction, and to indicate in a measure how they may be avoided.

To get along well with contractors and workmen the architect must feel sure that his opinions and decisions are correct, and *stick to them.* Of course one can often learn much from practical builders, but unless he is already somewhat informed upon the subject he is often likely to be imposed upon. In fact, one of the greatest troubles of young architects in superintending their buildings lies in the persistence with which builders and workmen will insist, often to the owner, that such and such methods or materials are the best for the purpose, or that the work should be done in such and such a way, or

that this or that requirement is unnecessary and not called for by older architects. Oftentimes these assertions are deliberate misrepresentations, made to save expense or labor, and unless the architect is well posted on the subject, and can quote good authorities for his views, it is difficult to combat them.

"The best workmen dislike to pull down or change what is already done, and if inadvertence or temporary convenience has led them into palpable violation of the specifications, they will often stretch the truth considerably in their explanation and excuse."

In pursuing his examinations of the work it is important that the architect or superintendent shall have a systematic plan, that all the innumerable points of construction shall receive attention at the proper time, and before they are covered up or built over so as to make changes inconvenient or impossible. If the superintendent is not also the architect, he should, before the work is commenced, carefully study the plans and specifications and make himself thoroughly familiar with all the points of construction, so that no important feature will be overlooked. He should carefully examine and verify all figures, to see that no mistakes have been made before the work progresses too far.

In making periodical visits to the building he should go all over the building and examine closely all work that has been done since his last visit. Wherever a man has been at work he should go and see what has been done. It is only in this way that the superintendent can insure against concealed defects or poor materials. When he is superintending several buildings at the same time, he should read the specifications and examine the plans frequently, to refresh his memory, otherwise he may overlook some features that cannot be as well attended to afterward.

Another important point in efficient supervision is, after inspecting the materials delivered, to make sure that those rejected are removed from the building, and not used during his absence. All defective materials should be marked in some way, *on their face,* so that they cannot be used without the mark showing, should the material be incorporated in the building. The superintendent should also insist that work which has been improperly done shall be taken down at once, and, if necessary, take it down or remove it himself. Any mistakes or bad work that are discovered should also be pointed out or condemned at the time, before they are driven out of the mind by other matters.

It is very essential that the superintendent shall, *at the start,* insist on having the work done as specified, and be very careful to reject all unfit material, for if the contractor finds him lenient at the start he will be sure to take advantage of it, and slight the work more and more. If, on the other hand, he finds that the work must be done right, or else rebuilt, he will be careful to do the work in such a way that it will not have to be done over again. A great fault with many superintendents is that they do not feel sufficient confidence in their own judgment and have not the courage to insist on their directions being followed.

In describing the different building operations the author has endeavored to call attention to the points that particularly need to be inspected, and to

some of the ways in which defective materials or construction are covered up. There are, the author is glad to say, many honest builders, who do not countenance bad workmanship, but the temptation to save money, especially when the work is taken at a low figure, is so great that the architect should consider that his duty to his client and to himself is not fulfilled until he has satisfied himself by careful inspection that the work is being done in the manner specified. Even when the contractor does not wish to slight the work, there are, unfortunately, many workmen who seem to prefer to do a poor job rather than a good one, and who, rather than lift a heavy stone, will break it in two, or save themselves all the labor possible, so long as their work will pass unnoticed.

For such the only treatment is to require a strict observance of the specifications and the superintendent's directions, with the certain penalty for violation of having to do their work over again.

Chapter I.

Foundations on Firm Soils

I. STAKING OUT THE BUILDING.

I. BATTER-BOARDS, BENCH-MARKS, LINES, ETC.—Except for city blocks, staking out the building is generally left to the contractor, but the superintendent should see that it is carefully done, and very often he is expected or called upon to assist in running the lines. The principal corners of the building should first be carefully located by small stakes driven into the ground, with a nail or tack marking the exact intersection of the lines. The lines should then be marked on *batter-boards*, put up as shown in Fig. I. Three

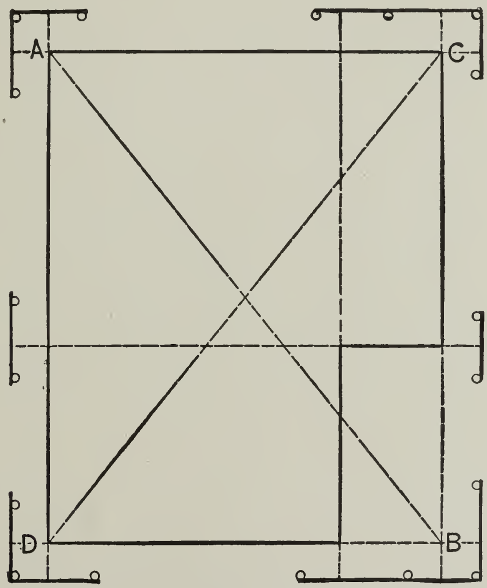


Fig. I. Plan of Lines, Stakes, Batter-Boards and Diagonals.

large stakes, two by four inches, or four by four inches, are firmly driven or set in the ground at each corner and from six to ten feet from the line of the building, according to the nature of the ground,

and fence-boards are nailed horizontally from the corner posts to each of the other two posts, as illustrated in Fig. 2. These boards should be long enough to allow both the inside and outside lines of the foundation walls to be marked on them. The stakes should also be braced from the bottom of each corner stake to the top of each of the others. This makes a firm support for the lines and one that need not be moved until the walls are up and ready for the first floor

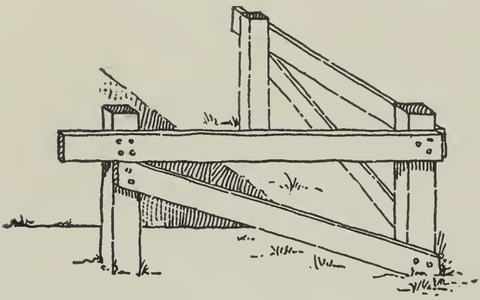


Fig. 2. Stakes and Fence-Boards.

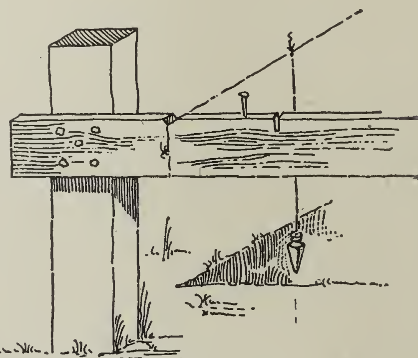


Fig. 3. Different Lines Indicated by Saw Marks, Nails and Notches.

joists. These boards have the great advantage over single stakes of being more permanent, and of allowing all projections of the walls, such as footings, basement wall and first story wall, to be readily marked on them. It is a good idea to indicate the ashlar line by a saw mark, the basement line by a nail and the footings by a notch, as shown in Fig. 3. In this way no mistake can be made by the workmen. If the tops of all the horizontal boards are kept on a level, it assists a great deal in getting levels for the excavating, etc.

The superintendent will be expected to furnish the contractor with a bench-mark, from which he can get the level for his footings, floor joists, etc. This mark should be put on some permanent object, where it can be referred to after the first floor joists are set in place. In giving such data to the contractor the superintendent must be very careful, as he can be held responsible for any loss resulting from errors which he may make. It is a very safe and good rule to give as few lines, data or measurements as possible to contractors, requiring them to lay out all the work themselves and to be alone responsible for the accuracy of their work.

2. LOT LINES, ETC.—For buildings which are built out to the street line, the lines of the lot should be given by a surveyor employed by the owner, and should be fixed by long iron pins driven into the street, or by lines cut on the curbstone across the street. In building close to the party-lines of a lot it is, of course, of great importance that the building does not encroach upon the adjacent lot, and to prevent this it is always well to set back one inch from the line, thus allowing for any irregularities or projections in the wall.

3. DIAGONALS.—After the batter-boards are in place and properly marked, the superintendent should require the contractor or his foreman to stretch the main lines of the building, and the superintendent should carefully measure the diagonals, as A B and C D, Fig. 1, with a steel tape; if they are not exactly of the same length the lines are not at right angles with each other and should be squared until the diagonals are of equal length.

On fairly level ground a building may be accurately laid out by means of a steel tape, using multiples of 3, 4 and 5 for the sides and the hypothenuse of a right-angled triangle. The larger the triangle the more accurate will be the work.

4. STAKING OUT BUILDINGS IN CITIES.—In staking out buildings in cities of the first and second class the building and property lines should always be obtained from an official survey, furnished at a nominal charge, by the surveyor of the district authorized by the city. It is usual also to have the district surveyor give the street and party-lines at the site of the operation. From these main lines the building may be readily staked out as described above.

In reading a survey care must be exercised to determine whether or not the measurements given are in United States standards, as frequently the unit measurements of the city and of the deeds are not standard, and may vary from the tape measurements as much as several inches in a hundred feet.

2. FOUNDATIONS. LIGHT BUILDINGS.

5. NATURE OF SOILS.—The architect should in all cases make every endeavor to discover the nature of the soil upon which his building is to be built before he makes his foundation plan. For most buildings a sufficient idea of the nature of the soil may be

gained by inquiry amongst builders who have put up buildings on the adjacent lots. Many soils, however, vary greatly, even in a distance of 100 feet, owing to a decided dip of the strata, and on all such soils much trouble and annoyance may often be saved by having borings made with a post-auger, showing the composition of the soil of the different strata. If two borings made on different sides of the site show about the same depth and character of soil it may be assumed that other borings would give the same result; but if the material brought up by the first two borings shows a difference in the character of the soil, or indicates that the strata have a decided dip, then borings should be made all around the foundations.

Where the ground has been filled in, or made, a knowledge of the original topography of the soil is always desirable. This information may sometimes be obtained from official county or city maps and is of great assistance in the designing of foundations for important buildings. The data thus obtained should, however, be supplemented by test borings in order to ascertain the character of the original superstratum.

For ordinary buildings borings to the depth of 8 or 10 feet are generally sufficient, although a 6- or 8-inch auger may be driven to the depth of 20 or 25 feet by two men using a lever. In soft soils a pipe must first be sunk and the auger worked inside of it. A smaller auger will answer in such cases.

For dwellings built on sand, gravel, clay or rock, an examination of the bottom of the trenches, and a few tests with an ordinary crowbar or post-auger, will generally be all that is necessary.

When borings are deemed necessary the owner should be advised of the fact, and his authority obtained for incurring the expense, which should be defrayed by him.

Different soils have not only different bearing or sustaining powers, but also various peculiarities which must be thoroughly understood and considered when designing the foundation.

An architect who, as a draughtsman, has had several years' experience in one locality before practicing for himself, will naturally have become acquainted with the peculiarities of the soil in that vicinity; but should his practice extend beyond his own city, he should carefully study the nature and peculiarities of the soil in each different locality where he may have work, and also obtain all the information possible, bearing on the subject, from local builders, as otherwise he may have serious trouble.

No part of a building is more important than the foundation, and more cracks and failures in buildings will be found to result from defective foundations than from any other cause; and for any such defects, resulting from the neglect of usual or necessary precautions, the architect is responsible to the owner, and also for the damage done to his own reputation.

The following observations are intended as a general guide in preparing foundations on different soils, although they should be supplemented by the experience of local builders wherever possible.

6. ROCK.—Rock, when it extends under the entire site of the building, makes one of the best foundation beds, as even the softest rocks will safely carry more weight than is likely to come upon them.

The principal trouble met with in building on rock is the presence of water. As the surface water cannot readily penetrate the rock it collects on top of the ledge and in the trenches so that some arrangement for draining it away should be provided. If the ledge falls off to one side, a tile or stone drain may be built from the lowest point of the footings to a point near the surface on the slope. If in a sewer district, the water may be drained into the sewer, proper precautions being taken for trapping and ventilation. If there is no sewer and the rock does not fall off, a pit to collect the seepage should be excavated at the lowest part of the cellar and an automatic arrangement provided for raising the water into a drain laid above the surface of the rock.

Fig. 4. Rock Cut to Level Planes.

To prepare the rock for the footings, the loose and decayed portions should be cut away and dressed to a level surface. If the surface of the rock dips, or is irregular in its contour, the portion under the footings should be cut to level planes or steps, as shown in Fig. 4. In no case should the footings of a wall rest on an inclined bed.

This method of filling in the depressions in rock excavation with concrete to a level bed in order to secure a firm footing is the one usually employed in the construction of all large buildings. In Fig. 5 is shown an example of this construction, illustrating the arrange-

ment of a column footing of the New York *Times* building, one of the heaviest structures in New York.

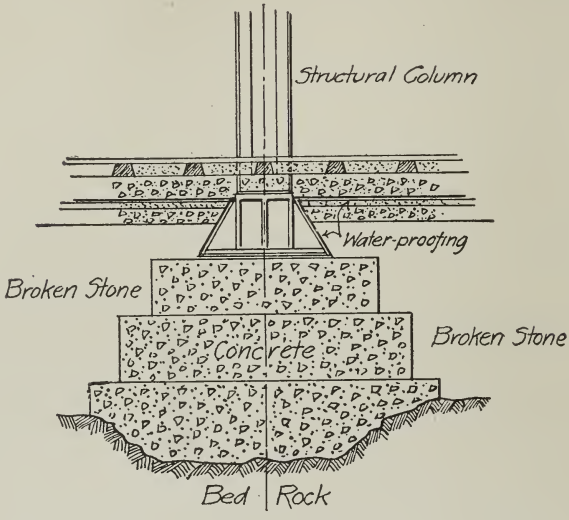


Fig. 5. Filled-in Rock Fissure, New York *Times* Building.

7. FISSURES AND DIFFERENT LEVELS.—If these are fissures or holes in the rock, they should be filled with concrete, well rammed; or, if a fissure is very deep, it may be spanned by an arch of brick or stone. In building on rock it is very desirable that the footings shall be nearly level all around the building; and whenever this is not the case, the portions of the foundation which start at the lower level should be laid in cement mortar and with close joints, as otherwise the foundations will settle unequally and cause cracks to appear above.

8. FOUNDATIONS PARTLY ON ROCK.—Should it be absolutely necessary to build partly on rock and partly on soil, the footings on the soil should be made very wide, so that the settlement will be reduced to a minimum. The footings resting on the rock will not settle, and the least settlement in those resting on the soil will be sure to produce cracks in the superstructure, and perhaps do other damage.

Building on such a foundation bed is very risky at best, and if possible should be avoided.

9. CLAY.—This soil is found in every condition, varying from slate or shale, which will support any possible load, to a soft, damp material, which will squeeze out in every direction when a moderately heavy pressure is brought upon it.

Ordinary clay soils, however, when they can be kept dry, will carry any usual load without trouble, but as a rule clay soils give more trouble than either sand, gravel or rock.

In the first place, the top of the footings must be carried below the frost line to prevent heaving, and for the same reason the outside face of the wall should be built with a slight batter and perfectly smooth surface. The frost line varies with different localities, attaining a depth of six feet in some of the Northern States, although between three and four feet is the usual depth reached. The effect of freezing and thawing on clay soils is very much greater than on other soils.

The surface of the ground around the building should be graded so that the rain water will run away from the building; and in most clays subsoil drains are necessary. When the clay occurs in inclined layers, great care must be exercised to prevent it from sliding; and when building on a side hill the utmost precautions must be taken to exclude water from the soil, for if the clay becomes wet the pressure of the walls may cause it to ooze from under the footings. The erection of very heavy buildings in such locations must be considered hazardous, even when every precaution is taken.

Frequently an excellent foundation soil is found underlaid with a thin stratum of clay. Where such a stratum exists there is little danger in building above it, provided there is no probability of adjacent excavations being carried below the clay and thus allowing it to be squeezed out by the pressure on the footings.

Should it be necessary to carry a portion of the foundations to a greater depth than the rest, the lower portion of the walls should be built as described in Article 7, and care must be taken to prevent the upper part of the bed from slipping. Wherever possible, the footings should be carried at the same level all around the building.

10. FOUNDATIONS IN HEAVY BLUE CLAY.—In Eastern Maine, where the soil is a heavy blue clay, and freezes to the depth of four feet, it is customary to build the foundation walls as shown in Fig. 6, the footings being laid dry, to act as a drain, and the bottom of the trench being slightly inclined to one corner, whence

a drain is carried to take away the water. The portion of the trench outside of the wall is also filled with broken stone or gravel to prevent the clay from freezing to the side of the wall. In the better class of work the outside of the wall is plastered smooth with cement. Sometimes a tile drain is laid just outside and a little below the footings.

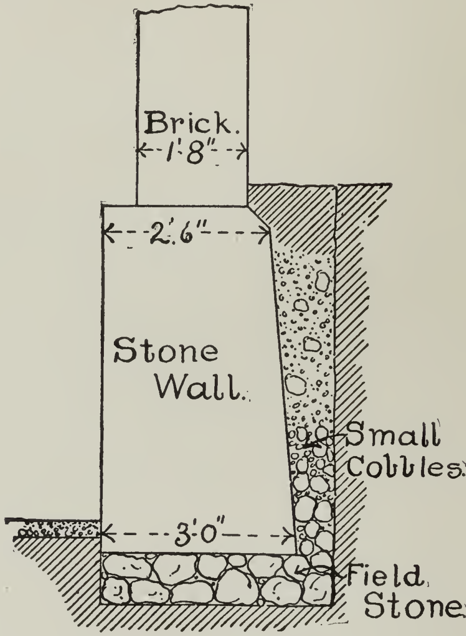


Fig. 6. Foundation in Clay, with Stone Drains.

11. CLAY WITH SAND OR GRAVEL.—If the clay contains coarse sand or gravel its supporting power is increased, and it is less liable to slide or ooze away.

In Colorado the top soil consists principally of clay, mixed with fine sand, and as long as it is kept dry it will sustain a great load without settlement. As soon as it becomes wet, however, it turns into a soft mud, which is very compressible and treacherous. For this reason the footings of heavy buildings are carried through the clay to the sand below. A peculiarity of this soil is that, although it freezes, it has never been known to *heave*. Two-story buildings are therefore often built on top of the ground, and as long as water is kept away from the walls no injury results.

12. GRAVEL.—This material gives less trouble than any other

as a foundation bed. It does not settle under any ordinary loads, and will safely carry the heaviest of buildings if the footings are properly proportioned. It is not affected by water, provided it is confined laterally, so that the sand and fine gravel cannot wash out. This soil also is not greatly affected by frost.

13. SAND.—This material also makes an excellent foundation bed when confined laterally, and is practically incompressible, as clean river sand compacted in a trench has been known to support 100 tons to the square foot.

As long as the sand is confined on all sides, and the footings are all on the same level, no trouble whatever is encountered, unless it is in the caving of the banks while making the excavations. Should the cellar be excavated to different levels, however, sufficient retaining-walls must be erected where the depth changes in order to prevent the sand of the upper level from being forced out from under the footings; and precautions should be taken in such a case to prevent water from penetrating under the upper footings.

14. LOAM AND MADE LAND.—No foundation should start on loam, that is, soil containing vegetable matter, or on land that has been made or filled in, unless the filling consists of clean beach sand, which, when settled with water, may be considered equal in resisting power to the natural soil.

Loam should always be penetrated to the firm soil beneath, and when the made land or filling overlies a firm earth the footings should be carried to the natural soil. When the filled land is always wet, as on the coast or on the borders of a lake, piles may be used, extending into the firm earth, and having their tops cut off below the low-water mark; but piles should never be used where it is not certain that they will be always wet.

15. MUD AND SILT.—Under this heading may be included all marshy or compressible soils which are usually saturated with water.

Foundations on such soils are generally laid in one of the three following ways: 1. By driving piles on which the footings are supported. 2. By spreading the footings either by wooden timbers, steel beams or reinforced concrete, so as to distribute the weight over a large area. 3. By sinking caissons or steel wells or cylinders, filled with masonry, to hard pan. As all of these methods are more or less complicated they will be described in Chapter II.

16. SOILS OF PECULIAR NATURE.—There are in some localities peculiar conditions in the soil strata with which those engaged in building operations should be familiar. In the anthracite regions, in some localities, the galleries or workings lie near the surface, and it is necessary to locate them with reference to the lines of the building so that the important piers may be extended down through them.

In one instance it was necessary to entirely rebuild a portion of a costly building in Scranton, Pa., because an apparently solid foundation soil was undermined by a subterranean stream which flowed along a shale substratum and then down into an abandoned mine-working. In this way the stream had tunnelled the upper stratum, so that when the weight of the almost completed building was imposed the earth gave way and caused dangerous settlement.

17. BEARING POWER OF SOILS.—The best method of determining the load which a particular soil will bear is the one involving direct experiment; but good judgment, aided by a careful examination of the soil, and particularly of its compactness and the amount of water it contains, in conjunction with the following table, will enable one to determine with reasonable accuracy its probable supporting power. A mean of the values given below may be considered safe for good examples of the kinds of soils quoted:

TABLE I.

Safe Bearing Strengths of Foundation Rocks and Soils.

CHARACTER OF SOIL.	TONS PER SQUARE FOOT
Rock, granite in hard, compact strata	100 to 200
Rock, limestone	25 to 30
Rock, sandstone	18 to 25
Rock, soft and friable, as shale	5 to 10
Clay, thick beds and dry	4 to 6
Clay, thick beds and moderately dry	2 to 4
Clay, soft	1 to 2
Gravel, mixed with sand and well cemented	8 to 10
Gravel, coarse and dry, well compacted	6 to 8
Sand, compact and well cemented	4 to 6
Sand, clean and dry and confined in natural beds	2 to 4
Quicksand, alluvial soils, etc	0.5 to 1

In case it is desirable to exceed the maximum loads here given, or in case there is any doubt of the bearing capacity of the soil or a lack of precedent, tests should be made in several places on the

bottom of the trenches to determine the actual load required to produce settlement, as described in Article 20.

18. MUNICIPAL REGULATIONS.—While Table I, giving the safe unit-bearing value of different foundation soils, represents conservative engineering practice, the municipal regulations of the locality must usually be observed, as the several cities have established such values in their building laws.

As a rule it is required that these values shall be used in proportioning foundation footings where the soil is not tested; and deviations are allowed from these values when the soil is tested, the test being witnessed by a representative of the building department and the record of the test being filed with the bureau.

The New York building law stipulates that the following loads per superficial foot shall be used in proportioning foundation footings: soft clay, one ton per square foot; ordinary clay and sand together, in layers, wet and springy, two tons per square foot; loam, clay or fine sand, firm and dry, three tons per square foot; very firm, coarse sand, stiff gravel or hard clay, four tons per square foot.

The Chicago building ordinance relating to the bearing value of foundation soils deals specifically with the soils underlying the city. These soils are of a clayey nature and the bearing value is limited as given in the following quotation from the ordinance:

"If the soil is a layer of pure clay at least fifteen feet thick without admixture of any foreign substance excepting gravel, it shall not be loaded more than at the rate of 3,500 pounds per square foot. If the soil is a layer of pure clay at least fifteen feet thick and is dry and thoroughly compressed, it may be loaded not to exceed 4,500 pounds per square foot.

"If the soil is a layer of dry sand fifteen feet or more in thickness, and without admixture of clay, loam, or other foreign substance, it shall not be loaded more than at the rate of 4,000 pounds per square foot.

"If the soil is a mixture of clay and sand it shall not be loaded more than at the rate of 3,000 pounds per square foot."

19. EXAMPLES OF ACTUAL LOADS AND TESTS.—*On Clay.*—The Capitol at Albany, N. Y., rests on blue clay containing from 60 to 90 per cent of alumina, the remainder being fine sand, and containing 40 per cent of water on an average. The safe load was taken at 2 tons per square foot. A load of 5.9 tons applied

on a surface 1 foot square produced an uplift of the surrounding earth.

The Congressional Library at Washington, D. C., rests on yellow clay mixed with sand. It was found that it required about 13½ tons per square foot to produce settlement, and the footings were proportioned for a maximum pressure of 2½ tons.

A hard indurated clay, containing lime, under the piers of a bridge across the Ohio River, at Point Pleasant, W. Va., carries approximately 2½ tons per square foot.

On Sand.—"In an experiment in France clean river sand compacted in a trench supported 100 tons per square foot.

"The piers of the Cincinnati suspension bridge are founded on a bed of coarse gravel 12 feet below water; the maximum pressure is 4 tons per square foot.

"The piers of the Brooklyn suspension bridge are founded 44 feet below the bed of the river, upon a layer of sand 2 feet thick, resting upon bed rock; the maximum pressure is about 5½ tons per square foot." *

20. METHODS OF TESTING.—Probably the easiest method of determining the bearing power of the foundation bed is the one involving the use of a platform from 3 to 4 feet square, having four legs, each 6 inches square. The platform should be set on the bottom of the trench, which should be carefully levelled to receive the legs. A level should then be taken from a stake or other bench-mark not liable to be disturbed, to each of the four corners of the platform, and the platform then loaded with dry sand, bricks, stone or pig-iron, as may be most convenient. The load should be put on gradually, and frequent levels taken until a sinkage is shown. From one-fifth to one-half of the load required to produce settlement is generally adopted for the safe load, according to circumstances. In testing the ground under the Congressional Library building a travelling car was used, having four cast-iron pedestals, set 4 feet apart each way, and each measuring 1 square foot at the base. The car was moved along the trenches, and halted at intervals in such a way as to bring the whole weight of the car and its load upon the pedestals which rested on the bottom of the trench. In this case the car was loaded with pig-lead.

By this method, if the legs of the testing apparatus do not settle evenly, it is impossible to tell just what the pressure on the lowest

* Ira O. Baker, *American Architect*, November 3, 1888.

corner amounts to; and it is not safe to consider it more than one-fourth of the whole load.

In testing soils by using a small square bearing area, it should be observed that the settlement will be in excess of that which would occur from the same load on a continuous footing. This is explained by the fact that the square end of the post or pedestal forming the bearing plate of the testing machine has four cutting edges which tend to enter the soil with less resistance than a long footing course having only two edges.

21. SOIL TESTING UNDER NEW YORK STATE CAPITOL.—In testing the soil under the State Capitol at Albany, N. Y., the load was placed on a mast 12 inches square, held in a vertical position by guys, and furnished with a cross frame to hold the weights. The bottom of the mast was set in a hole 3 feet deep, 18 inches square at the top and 14 inches square at the bottom. Small stakes were driven into the ground in lines radiating from the center of the hole, the tops being brought exactly to the same level, so that any change in the surface of the ground could readily be detected and measured by means of a straight-edge. In this case there was no change in the surface of the ground until the load reached 5.9 tons, when an uplift of the surrounding ground was noticed.

3. DESIGNING THE FOUNDATIONS.

22. PRELIMINARY DATA.—Knowing the character and supporting power of the soil on which he is to build, the architect is prepared to design his foundation plans, but in no case should this be done when the preceding information is wanting.

In designing the foundations the first point to be settled will be the depth of the foundations; the second, whether they shall be built in piers or in a continuous wall; and the third, the width of the foundations.

23. DEPTH.—For isolated buildings on firm soil, the depth of the foundations will generally be determined by the depth of the basement or by the frost line. Even where there is no frost, and the ground is firm, the footings should be carried at least 2 feet below the surface of the ground, so as to be below the action of the surface water. In very few soils, however, is it safe to start the foundations at a less depth than 5 feet, though in a temperate

climate, such as that of the Middle States, foundations carried to a depth of 3 feet 6 inches give little trouble. (See Article 10.)

The depth of the foundations for city buildings, built near the lot line, should be governed by the local laws bearing on the subject, by the character of the soil, and by the probable future action of the owners of the adjoining property.

In most cities the law provides that any lot owner who excavates below a certain depth, usually about 10 feet, must protect the walls of the adjoining property at his own expense; but that if he does not excavate below that depth, 10 feet, the adjoining owners must themselves protect their property from falling in.

It is, therefore, always wise to provide against any such future expense and trouble by carrying the footings, at least those of the side walls, to the prescribed limit, above which the owner will be responsible, even if the requirements of the soil or building do not necessitate it. This precaution is especially important when the building is erected on sand.

24. CONTINUOUS FOUNDATIONS VERSUS PIERS.— It has been found that when heavy buildings are to be erected on soft or compressible soils greater security from settlement may be obtained by dividing the foundation into isolated piers, as described in Chapter II.

When building on firm soils, however, no advantage is gained by pursuing this method, unless the walls of the building are themselves composed of piers with thin curtain-walls between, in which case the foundations under the piers and walls should be built of different widths, and not bonded together, as described in Article 33.

When the walls are continuous, however, and of the same thickness throughout, the foundation should be continuous. The architect should constantly bear in mind that in all kinds of building construction the simplest methods are almost always the best, and that complicated arrangements and the use of iron, etc., in foundations, at least on firm soils, should be avoided.

25. PROPORTIONING THE FOOTINGS. — Whether the foundations are continuous or divided into piers, the area of the footings should be carefully *proportioned to the weight which they support* and to the bearing power of the soil. The former is perhaps the most important of all considerations in designing the footings. While the safe bearing power of the soil ought not to be

exceeded, it is, on most soils, not of so much importance as a proportioning of the footings, such that the *pressure on the soil from every square foot of the footings will be the same.* If this condition always obtained there would be few cracks in the mason work of buildings, as such cracks are caused, not by a uniform settlement of an inch or two, which with most buildings would not be noticed, but by an *unequal* settlement.

In proportioning the area of the footings the architect should carefully compute the weights coming upon each pier, and the weight of and the loads supported by the walls, and record the same in a memorandum book or otherwise file for reference.

He should then decide, by means of Table I, Article 17, and by an examination of the ground, or, if necessary, by actual tests, the bearing weight which it appears advisable to assume. By dividing the load on the various footings by this assumed carrying load, the proper area of the footings will be found.

The pressure under piers supporting a tier of iron columns may be made 10 per cent more than that under a brick wall, so that the piers may settle a little more to allow for the compression in the joints of the mason work.

26. COMPUTING THE WEIGHT.—*In computing the weight* to be supported by the footings the live or movable loads and the dead loads should be computed separately. In building on any compact soil, the object in carefully proportioning the footings, as has been stated, is not so much to prevent any settling of the building as a whole, but to provide for a uniform settling of all portions of it, so that the floors will remain level and no cracks be developed in the walls. In order to secure this result, it is necessary that the loads for which the footings are proportioned shall agree with the actual conditions as closely as possible.* Thus the dead load under the walls of a five-story building would be a considerable item, while the dead load under a tier of iron columns would be much less in proportion to the floor area supported; and, as the dead load is always constant and the live load one which may greatly vary, only the amount of the live load that will *probably* be supported by the footings *most of the time* should be considered.

For warehouses, stores, etc., about 50 per cent of the live load for

* Foundations shall be proportioned to the actual average loads they will have to carry in the completed and occupied building, and not to theoretical or occasional loads.—*Chicago Building Ordinance.*

which the floor beams are proportioned should be added to the dead load supported on the footings.

For office buildings, hotels, etc., the weight of the people who occupy them should be neglected altogether in proportioning the footings, and only about 15 pounds per square foot of floor allowed to cover the weight of furniture, safes, books, etc. Actual statistics show that the permanent average loads in such buildings do not exceed the above limit.

For theatres and similar buildings some allowance should probably be made for the weight of people, the actual amount depending upon the arrangement of the plan and character of the soil.

27. BUILDING ORDINANCES.—While the data given above represent conservative practice in regard to the percentage of the live load to be assumed in designing foundations, it must be observed that this is regulated by law in the larger cities.

Many building codes throughout the country are compiled, with modifications, from the code of the city of New York, so that the following quotation from the portion of the code relating to the proportioning of footings will be found useful here:

"The loads exerting pressure under the footings of foundations in buildings more than three stories in height are to be computed as follows: For warehouses and factories they are to be the full dead load and the full live load established by this code. In stores and buildings, for light manufacturing purposes, they are to be full dead load and 75 per cent of the live load established by this code. The same applies to churches, school-houses and places of public assembly. In office-buildings, hotels, dwellings, apartment-houses, tenement-houses, lodging-houses and stables, they are to be the full dead load and 60 per cent of the live load established by this code. The footings must be designed to distribute the loads as uniformly as possible, so as not to exceed the safe bearing capacity of the soil as established by this code."

28. LIVE LOADS AND UNEQUAL SETTLEMENTS.—Almost any soil, after it has been compacted by the dead weight of a building, will carry a shifting load of people without further settlement; while if the footings are computed to carry the full live loads for which the floor beams are designed, it will be found that when the building is finished the actual loads on the footings under the walls will be much greater than under the interior piers; and if

the ground settles at all during building the probabilities are that the floors of the building will be higher in the middle than at the walls.

29. CALCULATIONS FOR FOOTING WIDTHS.—*Example I.*—Assume that a six-story and basement warehouse is to be erected on an ordinary sand and gravel foundation. The building is to be 50 feet wide, with two longitudinal rows of columns and girders. What should be the width of the footings under the walls and columns?

Solution.—The load on one lineal foot of footing under the side walls will consist of about 140 cubic feet of brick and stone work, weighing about 17,000 pounds.* One lineal foot of wall will also support about 8 square feet of each floor and the roof. Assume also that the floors are of steel beams and terra-cotta tile, with concrete filling, weighing altogether 75 pounds to the square foot, and that the roof is of the same material, weighing 60 pounds to the square foot. Then the dead load from the six floors and roof will amount to 4,080 pounds. The first, second and third floors are intended to support 150 pounds to the square foot, and those above 100 pounds to the square foot. The possible weight of snow on the roof will not be taken into account. There might then be a possible live load on the footing of 6,000 pounds, but as it is improbable that each floor will be loaded all over at the same time, and as some space must be reserved for passages, etc., the actual live load will probably not exceed for any length of time 50 per cent of the assumed load, or 3,000 pounds. Adding these three loads together, the wall loads, floor loads and live loads, there results 24,080 pounds as the load on one lineal foot of footing. By allowing 6,000 pounds, 3 tons, for the bearing power of the soil, and by dividing the load by this amount, the required width of the footing is found to be 4 feet. The load on the footings under the columns will consist only of the weight of the floors, roof and live load, plus the weight of the tier of columns, which will be so small in proportion to the other loads that it need not be considered. If the columns are 14 feet apart longitudinally, each one will support 224 square feet of each floor, so that the total dead load on the footing under the columns will amount to 114,240 pounds, and the possible live load will amount to 168,000 pounds. As it is hardly possible for every square foot of floor in every story to be loaded to its full capacity

* For weight per cubic feet of materials, see table in Appendix.

at the same time, it will probably be nearer the actual conditions if only 50 per cent of the total live load, or 84,000 pounds, are taken, making a total load on the footing of 198,240 pounds, which will require 33 square feet in the area of the footing. But as there will be no shrinkage or compression in the iron columns, it will be better to reduce this area 10 per cent, making the footing 5½ feet square, with an area slightly in excess of 30 square feet.

The above calculation should be filed, or entered in a memorandum book, kept for the purpose, somewhat as follows:

DATA FOR FOOTINGS.

	UNDER ONE FT. OF SIDE WALLS.	UNDER COLUMNS.
Cubic feet of brickwork,	108 @ 120 = 12,960 lbs.	
Cubic feet of stonework,	28 @ 150 = 4,200	
Total weight of wall	17,160 lbs.	Nothing
Floor area supported 8 □'		16 × 14 = 224 □'
Weight of floors per □' 75 lbs.		
Weight of roof per □' 60 lbs.		
Total for six floors and roof: 510 × 8 =	4,080	510 × 224 = 114,240
Live load per □'—		
1st, 2d and 3d floors, 150 lbs.		
3d, 4th and 5th floors, 100 lbs.		
Total live load, 8 × 750 = 6,000		750 × 224 = 168,000
50% of this =	3,000	84,000
Total load	24,240	198,240
Assumed bearing load, 6,000 lbs.		
Width of footings under wall, 4 ft.; under columns, 33 □' less 10%, or 5' 6" × 5' 6".		

The front and rear walls, if continuous, would not have to support any floor loads, and the footings should be reduced in proportion. The footings under the piers supporting the ends of the girders should also be separately computed.

30. FOOTING WIDTHS IN GENERAL.—In the case of light buildings it will often be found that the computed width of footings will be less than that required by the building ordinances, in which case it will of course be necessary to comply with such ordinances or building laws. As a rule, the footings under a foundation wall should be at least 12 inches wider than the thickness of the wall to give it stability. Even in light buildings the footings under the different portions of them should be carefully proportioned, so that all will bring the same pressure per square foot on the ground. In cases where the width of the footing is regulated by the building law, the pressure per square foot under the footing should be computed, and the footings under all piers, etc., proportioned to this standard. In cases where a high tower

adjoins a lower wall the footings under the two portions must be carefully proportioned to the weight on each; otherwise the wall may crack where it is bonded into the tower.

31. CALCULATIONS FOR FOOTING WIDTHS.—*Example II.*—To illustrate the manner in which the width of the footings should be proportioned when the pressure under the footings is very light, the following example will be considered:

A one-story stone church has side walls 20 inches thick and 22 feet high above the footings and a tower at the corner 60 feet high, the first 22 feet being 24 inches thick and the balance 20 inches thick. The roof is supported by trusses and purlins, so that only the lower 6 feet of the roof rest on the side walls. The side walls also carry 6 feet of the floor. The tower has a flat roof 12 feet square.

Solution.—The computations for the widths on the soil under the side walls and under the tower wall will be as follows:

UNDER SIDE WALLS.	
Stonework, 22′ × 20″ = 36⅔ cu.ft. at 150 lbs. per cu.ft.,	5,500 lbs.
Weight of first floor, 130 lbs. × 6 □′ =	780 "
Weight of roof below purlin, 40 lbs. × 6 □′ =	240 "
Total weight on soil......	6,520 "

UNDER TOWER WALL.	
Stonework, 22′ × 24″ = ...	44 cu. ft.
38′ × 22″ = ...	63⅓ "
107⅓ × 150 = ...	16,100 lbs.
Weight of floor, 130 × 6 = ..	780 "
Weight of roof, 40 × 6 = ..	240 "
Total weight on soil.....	17,120 "

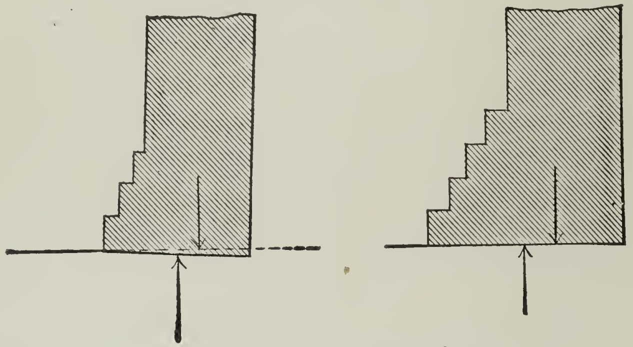
Width of footings, 3 ft.
Pressure per □′ under footings, 2,173 lbs.
Width of footings under tower, 17,120 ÷ 2,173 = 7.8 ft.

In this case the width of the footings under the side wall should be determined by the question of stability, and should not be less than 3 feet. Then if the pressure under the tower is reduced to the same unit per square foot, the tower footings will need to be nearly 8 feet wide. On firm soils, however, such as sand, gravel or compact clay, it will not be necessary to make the footings as wide as this, as the soil will probably not settle appreciably under a considerably greater pressure; so that if the footings of the tower are made 6 feet wide, there will probably be no danger of unequal settlement. Of course the greater the unit pressure on the soil the more exact must be the proportioning of the footings.

32. CENTER OF PRESSURE TO COINCIDE WITH CENTER OF BASE.—In order that the walls and piers of a building may settle uniformly and without producing cracks in the superstructure, it is not only essential that the area of the footings

shall be in proportion to the load and to the bearing power of the soil, but also that the *center of pressure* (a vertical line through the center of gravity of the weight) *shall pass through the center of the area of the foundation.*

This condition is of the first importance, for if the center of pressure does not coincide with the center of the base the ground will yield the most on the side which is pressed the most; and as the ground yields, the base assumes an inclined position and carries the lower part of the structure with it, thus producing unsightly cracks, if nothing more.



Center of Pressure and Center of Base.
Fig. 7. Narrow Offsets. Fig. 8. Wide Offsets.

A case in which a violation of this rule cannot well be avoided is the case of a foundation under the side wall of a building, where the footing is not allowed to project beyond the lot line. In this construction the center of pressure is indicated by the downward arrow, and the center of base by the upward arrow, Fig. 7. It is evident that the intensity of the pressure is greatest on the portion of the footing to the right of the center of base, and the footing will consequently settle obliquely, as shown in the figure, with a tendency to throw the wall outward. This tendency may be counteracted by tying the wall securely to the floor joists, but it is much better to make some arrangement by which the footing will settle evenly. Where it is absolutely necessary to build the footing without projecting beyond the lot line, the former should be carefully built of concrete, dimension stone or hard bricks well grouted in cement mortar, and the footing should be no wider than is absolutely demanded by the nature of the soil. The offsets on the inside of the wall should be so proportioned that a line drawn through their

edges will make an angle of not less than 60 degrees with the horizontal. The footing shown in Fig. 7 is to be preferred to that shown in Fig. 8.

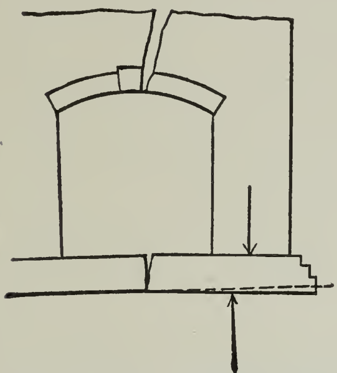


Fig. 9. Center of Pressure Outside of Center of Base.

Sometimes the center of pressure or of weight is inside of the center of resistance of the soil, a result due to the concentration of heavy beam or girder loads toward the inside edge of the wall. Where this condition exists the tendency is to incline the wall inward, and this, instead of diminishing, tends to increase the stability of the structure, as the floor systems, and the opposite and adjacent walls, preclude the possibility of any failure in this direction.

33. CRACKS IN BUILDINGS.—Fig. 9 illustrates another case in which the center of pressure comes outside of the center of base, and in consequence of which the wall inclines outward, producing cracks over the opening. This is a very common occurrence in brick and stone walls in which there are wide openings. In such cases the footing under the opening should either be omitted entirely or made narrower there than it is under the pier, and the two footings should not be bonded together. Where several openings occur one above the other, as in Fig. 10, and the footings are con-

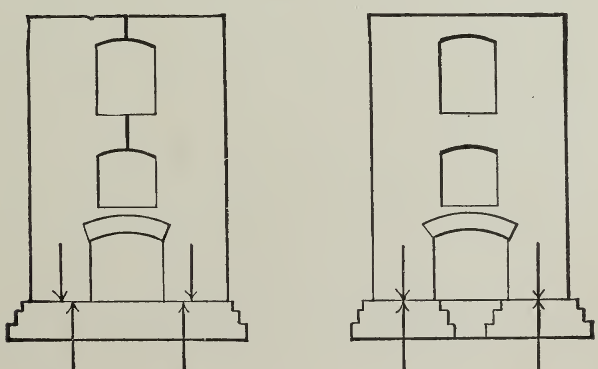


Fig. 10. Incorrect Method. Continuous Wall.

Fig. 11. Correct Method. Separate Piers and Dwarf Walls.

tinued under the opening, the unequal settlement of the footings will very likely produce cracks over all the openings, the side walls inclining slightly outward. Where the width of the opening is 8 feet or more, and the bottom of the opening is not a great distance above the footings, the latter under the wall on each side should be treated as if they were under piers, as shown in Fig. 11, and the space between the footings should be filled in with a dwarf wall only. If the bottom of the opening is twice its width above the foundation, the wall under it will distribute the weight equally over the footings and the settlement will be uniform.

As a rule the foundation of one wall should never be bonded into that of another which is either much heavier or much lighter than itself.

The footings should also be proportioned so that the center of pressure will fall a short distance *inside* of the center of the base, in order to make sure that it will not fall *outside* of it. Any inward inclination of the wall, as previously explained, is rendered impossible by the interior walls and by the floors, while any outward inclination can be conteracted only by anchors and by the bond of the masonry. A slight deviation of the center of pressure outside of the center of base has a marked effect, and is not easily counteracted by anchors.

In Chicago an omission of from 1 to 2 per cent of the weight, by leaving openings, usually causes sufficient inequality in the settlement to produce unsightly cracks.*

Where slight differences in weight occur, cracks may generally be prevented by building in hoop-iron ties, rods or beams over the openings. It is also a wise precaution, where one wall joins another, either in the middle or at the corner of a building, to tie the walls together by long iron anchors built into the walls about every six feet in height.

34. FOOTINGS AT DIFFERENT LEVELS.—In all cases where the foundations of a new building go down to a greater depth than those of an existing adjacent building care must be taken to prevent the earth from sliding from under the footings of the existing building, and threatening its destruction. Usually the only safe plan is to resort to "underpinning" as described in Chapter III.

* Ira O. Baker in "Masonry Construction."

It should be observed also that many basement plans of important buildings provide for different floor levels in the several sections of the building. For instance, the boiler-room and engine-room may be carried down in order to provide greater head-room. In such cases the position of each column and wall footing should be examined to see if it is deep enough to prevent the pressure upon it from forcing out the earth into the more deeply excavated

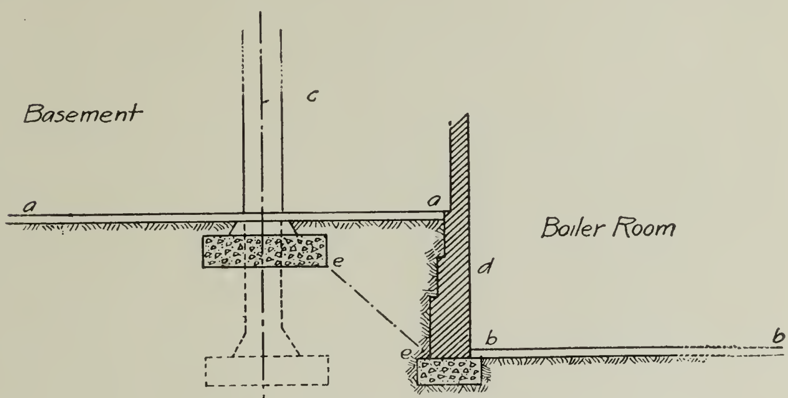


Fig. 12. Footings at Different Levels.

area. This condition is illustrated in Fig. 12, which shows the normal basement level at *a, a,* and the boiler-room floor level at *b, b.* At *c* is shown one of the important column piers of the structure, with its footing near the deeper excavation and at a higher level. The great pressure on the column footing tends to force the earth out from under it, and to overturn the retaining wall at *d,* and the footing should be carried down to the level indicated by the dotted lines. When the soil is very stable a footing of this nature may generally be considered safe, if the line *e, e* makes an angle of not more than 30 degrees with the horizontal. It is also necessary in designing foundations to see that column and wall footings are deep enough to permit the installation of engine foundations, tanks or sumps without endangering the footings.

4. SUPERINTENDENCE.

35. MATTERS REQUIRING SPECIAL ATTENTION.—In inspecting the excavation the superintendent should first examine the lines to see that the building has been correctly staked

out, and that the excavation is being carried at least 6 inches outside of the wall lines, so as to give room for pointing or cementing. If the walls are built against the bank it will be impossible to point up the joints on the outside, and the back of the walls not being exposed, the masons are apt to slight that part of the work to the future detriment of the building; and if the excavation is not made large enough at first, it causes much trouble and vexation, as the work cannot be done as cheaply afterward, and the stone-masons will very likely complain about being delayed.

The superintendent should also see that the finished grade is plainly marked on some fixed object and should caution the workmen not to dig the trenches below the levels marked on the drawings. If the trenches are excavated below the proper levels, they must not be refilled with earth, as the footings should start on the solid bottom of the trenches; and as this will require more masonry than the contractor estimated on, he will be quite sure to call for an extra payment for the same from the owner, unless the excavating is included in his contract, in which case he will have to settle with the excavator. For this reason it is a good plan to have the excavating included in the contract for the foundation.

It is good practice, also, and especially in the construction of heavy buildings, to have the bottom of footing trenches and pier excavations thoroughly rammed so as to further compress the soil before the footings are put in.

The superintendent should also examine the character of the soil at the bottom of the excavation, and if he finds that it is not such as was expected, the foundations should be changed or carried deeper, as previously described. In case water is encountered in making the excavations, some provision should be made for draining the cellar, either by laying tile drains around the footings, or by laying the bottom courses dry and connecting them with stone drains, as described in Articles 6 and 10. The specifications should provide that the contractor is to keep the trenches free from water while the walls are being built. In places where the water cannot be drained off it must be removed by a pump, either worked by hand or by steam. When the excavation is made close to an adjoining building the superintendent should see that the contractor has made proper provision for shoring or otherwise protecting the adjacent walls.

Chapter II.

Foundations on Compressible Soils

36. COMPRESSIBLE SOILS IN GENERAL.—The soils of this class that are met with in preparing the foundations of buildings are often located along the shores of large bodies of water and hence generally permeated with moisture to within a few feet of the surface.

For such soils pile foundations are usually the cheapest and most reliable. On a soil like that underlying Chicago, and having a supporting power of from 1½ to 2½ tons per square foot, spread foundations may be used with satisfactory and economic results, whereas it would require piles over 40 feet long to reach hard-pan.

Occasionally it is necessary to build on ground that has been filled in to a considerable depth, and in which water is not present; and in that case timber piles cannot be used. In such cases wells of solid masonry with iron casings, or pneumatic caissons, may be sunk to bed-rock or hard-pan, as hereinafter described, or concrete piles may be used.

1. PILE FOUNDATIONS

37. OBJECTIONS TO PILE FOUNDATIONS.—When it is necessary to build on a compressible soil that is *constantly saturated* with water and of considerable depth, the cheapest and generally the best foundation bed is obtained by driving wooden piles. Pile foundations cannot always be used without danger to adjoining buildings because the method of driving generally employed is liable to jar and weaken the neighboring walls and foundations. It has also been claimed that driving piles in a soil such as that under Chicago, within a few feet of buildings having spread-foundations, has a tendency to cause the latter to settle so as to necessitate underpinning.

On driving the first piles for the Schiller building, Chicago, it was found that an adjoining building had settled 6 inches, and it had to be raised on screws.

The driving of piles also causes a readjustment of the particles of

clay and sand into a jelly, thus greatly diminishing the resisting properties. These objections, however, are not of so much moment when the adjoining buildings are supported by piles.

38. CLASSES OF PILES.—A great many kinds of piles are used in engineering works, but for the foundations of buildings wooden piles are at present used oftener than any other kind.

The different conditions under which piles are used for supporting buildings may be classed as follows:

1. When the compressible soil is not more than 40 feet deep and overlies a bed of rock, gravel, sand or clay, long piles should be driven to the rock, or to a distance of from one to two feet into the clay or sand, in which cases they may be considered to act as columns.

2. If the soft soil is more than 40 feet deep, piles varying from 15 to 40 feet in length should be driven, according to the character of the soil, the sustaining power of the piles depending upon the friction between the pile and the surrounding soil.

3. Short piles, from 10 to 15 feet in length, are sometimes driven, particularly in Southern cities, in order to consolidate the soil and to give it greater resisting power. As piles are seldom used in this way, this method of forming a foundation bed will be dismissed with the following quotation:

39. FOUNDATIONS ON SOFT ALLUVIAL SOILS.—"In some sections of the country, especially in the Southern cities, the soil is of a soft alluvial material, and in its natural state is not capable of bearing heavy loads. In such cases trenches are dug as in firm material, and a single or double row of short piles are driven close together, and under towers or other unusually heavy portions of the structure the area thus covered is filled with these piles. The effect of this is to compress and compact the soil between the piles, and to a certain extent around and on the outside, thereby increasing its bearing power; whatever resistance the piles may offer to further settlement may be added, though not relied upon. These piles are then cut off close to the bottom of the trench, and generally a plank flooring is laid resting on the soil and piles, or a layer of sand or concrete is spread over the bottom of the trench to the depth of 6 inches or 1 foot, and the structure, whether of brick or stone, commenced on this. There is little or no danger of such structures settling, and if they do the chances are that they will settle uniformly if the number of piles are properly proportioned to the weight di-

rectly above them; but if the piles are not so proportioned the same number being driven under a low wall as under a high wall, unequal settlement is liable to take place, causing ugly or dangerous cracks in the structure."*

A. WOODEN PILES

40. MATERIAL.—Wooden piles are made from the trunks of trees and should be as straight as possible, and not less than 5 inches in diameter at the small end for light buildings or 8 inches for heavy buildings. The woods generally used for piles in the Northern States are spruce, hemlock, white pine, Norway pine, Georgia pine, and occasionally oak, hickory, elm, black-gum and basswood. In the Southern States, Georgia pine or pitch pine, cypress and oak are used. The tougher and stronger woods are the best for timber piles, especially where they are to be driven to hard-pan, and heavily loaded. There is little difference in the durability of these various woods under water. Oak is considered the most durable wood for piles, and also the toughest, but it is too expensive for general use in the Northern States, besides being difficult to obtain in long, straight pieces. Next to oak come Georgia pine, Oregon pine, cypress and spruce, in the order named.

Of the 1,700 piles supporting the Illinois Central Railway Station in Chicago, 32 per cent were black-gum, 22 per cent pine, 7 per cent basswood, 21 per cent oak, 15 per cent hickory, with a few maple and elm. A smaller proportion of the hickory piles were broken or crushed than of any other wood.

41. POINTING WOODEN PILES.—Piles should be prepared for driving by cutting off all limbs close to the trunk, sawing the ends square, and removing the bark. The removal of the bark is probably of not very great importance, as many piles are driven with the bark on. The small end of each pile should be sharpened to a point 2 inches square, the bevel being from 18 to 24 inches long. The large end should be cut square to receive the blows from the hammer.

Experience has shown that in soft and silty soils the piles can be driven in better line without pointing. A pointed pile, on striking a root or similar obstruction, will inevitably glance off, and no available power can prevent it from doing so, while a blunt pile will cut or break the obstruction without being diverted from its position.

* "A Practical Treatise on Foundations." W. M. Patton.

When driving into compact soil, such as sand, gravel or stiff clay, the point of the pile is often shod with iron or steel, either in the form of a strap bolted to the end of the pile, as at *a*, Fig. 13, or by a conical cast-steel shoe about 5 inches in diameter, having a 1¼-inch dowel 12 inches long fitting into a hole in the end of the pile and a ring fitting around the pile, as shown at *b*, to prevent it from splitting. The latter method should be used in very hard soils. If a strap is used, as at *a*, it should be 2½ inches wide, ½ an inch thick and 4 feet long.

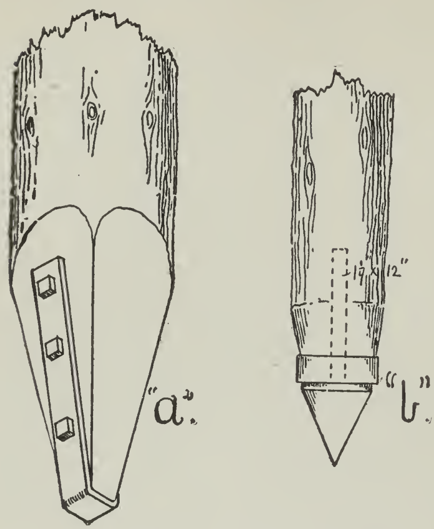


Fig. 13. Straps and Shoes for Piles.

42. RINGING WOODEN PILES.—When the penetration at each blow is less than 6 inches, the top of the pile should be protected from "brooming" by putting on an iron ring about 1 inch less in diameter than the head of the pile, and from 2½ to 3 inches wide by ⅝ of an inch thick. It is better to chamfer the head so that the ring will just fit on than to drive the ring into the wood by the hammer, as the latter method is liable to split long pieces from the pile.

43. PROTECTION OF WOODEN PILES.—Piles that are to be driven in, or exposed to, salt water should be thoroughly impregnated with creosote, dead oil of coal-tar, or some mineral poison to protect them from the "teredo" or ship worm, which will completely honeycomb an ordinary pile in three or four years.

44. DRIVING WOODEN PILES WITH THE DROP-HAMMER.—The usual method of driving piles is by a succession of blows given with a block of cast-iron called the hammer, which works up and down between the uprights of a frame or machine called a pile-driver. The machine is placed over the pile, so that the hammer descends fairly on its head, the piles always being driven with the small end down. The hammer is generally raised by steam power furnished by a hoisting engine, and is dropped either automatically or by hand. The usual weight of the hammers used for

driving piles for building foundations is from 1,500 to 2,500 pounds, and the fall varies from 5 to 20 feet, the last blows being given with a short fall. Heavier hammers than these are sometimes, but not often, used, occasionally weighing 4,000 pounds and over.

In driving piles care should be taken to keep them plumb, and when the penetration becomes small the fall should be reduced to about 5 feet, the blows being given in rapid succession.

Whenever a pile refuses to sink under several blows, before reaching the average depth, it should be cut off and another pile driven beside it.

When several piles have been driven to a depth of 20 feet or more and refuse to sink more than ½ an inch under five blows of a 1,200-pound hammer falling 15 feet, it is useless to try them further, as the additional blows only result in brooming and crushing the heads and points of the piles, and in splitting and crushing the intermediate portions to an unknown extent.

"Sometimes piles drive easily and regularly to a certain depth, and then refuse to penetrate farther. This may be caused by a thin stratum of some hard material, such as cemented gravel and sand or a compact marl. It may require many hard and heavy blows to drive through this, thereby injuring the piles, and perhaps getting into a quicksand or other soft material, when the pile will drive easily again. If the depth of the overlying soil penetrated is sufficient to give lateral stability, or if this can be secured by artificial means, such as throwing in broken stone or gravel, it would seem unwise to endeavor to penetrate the hard stratum, and the driving should be stopped after a practical refusal to go with two or three blows. The thickness of this stratum and the nature of the underlying material should be determined either by boring or by driving a test pile, to destruction if necessary. In the latter case the driving of the remaining piles should cease as soon as the hard stratum is reached." *

If the hard stratum, however, is only 2 or 3 feet thick, with hard-pan not more than 40 or 50 feet from the surface, the piles should be driven to hard-pan for heavy buildings; but if the soft material continues for an indefinite depth below the hard stratum, the piles should be stopped when the stratum is reached. In such cases, however, the actual bearing power of the piles should be tested by loading one or more of them, as described in Section 50.

* "A Practical Treatise on Foundations." W. M. Patton.

45. DRIVING WOODEN PILES WITH THE STEAM-HAMMER.—There are two other methods of driving piles commonly employed, namely: with the steam-hammer, and by the water-jet process. By the former method a specially constructed steam-hammer, in contact with or attached to the head of the pile, strikes a rapid succession of blows which cause the pile to penetrate rapidly, because the earth at the penetration point of the pile is not allowed time to compact and readjust itself after each blow. The blows struck are comparatively light, and the head of the pile does not broom and break up as much as under the hammer of the ordinary pile-driver. Because of this the pile used under a steam-power hammer may be of poorer quality and softer wood than would ordinarily be used under a drop-hammer, and the pile in driving may be kept more easily in line.

46. DRIVING WOODEN PILES WITH THE WATER-JET.—Piles may be driven by means of a water-jet, and sometimes both the drop-hammer and water-jet are used in conjunction. In using the water-jet for sinking piles a piece of pipe or rubber hose, from 1½ to 2½ inches in diameter, is secured to the pile with staples in such a manner that it may be withdrawn after the pile is driven. The piece of pipe or hose passes down to the end of the pile, and is connected at the upper end with a pump and provided at the lower end with a nozzle, usually from 1 inch to ⅞ of an inch in diameter. Under operation the force of the water scours out and liquefies the soil beneath and around the pile, so that it sinks by its own weight or the weight of the operating platform brought to bear upon it.

This method of driving operates the best in soils consisting mostly of sand, soft clay or mud, though it may be used in nearly all soils except hard-pan or rock. Generally the best results are obtained by this process when a considerable volume of water is delivered at a moderate velocity, as the rapid penetration of the pile depends more upon the fluidity created in the surrounding soil than upon the scouring action of the jet. The water-jet process is much used for sinking piles for piers, breakwaters and jetties in sandy beaches, but is not used to such a great extent for building construction as the amount of water used is in most instances objectionable.

47. BEARING POWER OF WOODEN PILES.—When driven in sand or gravel, or to hard-pan, piles will carry to the full extent of the crushing strength of the timber, providing their depth is sufficient to secure lateral stiffness.

"There are examples of piles driven in stiff clay to the depth of 20 feet that carry from 70 to 80 tons per pile. There are many instances in which piles carry from 20 to 40 tons under the above conditions. After a pile has been driven to 20 feet in sand or gravel, any further hammering is a waste of time and money, and injurious to the pile itself." *

Piles driven from 30 to 40 feet in even the softest alluvial soils should carry by frictional resistance alone from 10 to 12½ tons.

TABLE II.

Safe Bearing Value of Wooden Piles in Different Soils.

SOIL.	PILE LENGTHS.	AVERAGE DIAMETER	PENETRATION.	LOAD IN TONS.
	Ft.	Ins.	Ins.	
Silt	40	10	6	2¼
Mud	30	8	2	6
Soft earth with boulders or logs	30	8	1½	7
Moderately firm earth or clay with boulders or logs	30	8	1	9
Soft earth or clay	30	10	1	9
Quicksand	30	8	½	12
Firm earth	30	8	½	12
Firm earth into sand or gravel	20	8	¼	14
Firm earth to rock	20	8	0	20
Sand	20	8	0	20
Gravel	15	8	0	20

The bearing value of a pile depends upon the distance which it penetrates the soil under the final blows of the hammer; so that, when this distance is known, together with the weight and the height of fall of the hammer, the probable bearing value of the pile may be determined. The values given in Table II, which follows, show the probable penetration of piles of different lengths when driven into the different kinds of soil usually encountered. The safe bearing values in tons, given in the last column of the table, are calculated from the *Engineering News* formula, which is explained in the following article. The values given in the table are for minimum lengths of spruce piles and average penetrations for the last five blows of a 1,200-pound hammer falling 15 feet. When heavier loads than these must be carried, or when the penetration is much greater, the actual bearing power of the piles should be determined by testing, unless it is already known from actual experience.

* "A Practical Treatise on Foundations." W. M. Patton.

48. FORMULA FOR THE SAFE WORKING LOAD ON PILES.—There have been several formulas proposed for determining the safe working loads on piles. Of these, one of the latest, known as the *Engineering News* formula, is generally considered to be the most reliable. It is claimed for this formula that it sets "a definite limit, high enough for all ordinary economic requirements, up to which there is no record of pile failures, excepting one or two dubious cases where a hidden stratum of bad material lay beneath the pile, and above which there are instances of both excess and failure, with an increasing proportion of failures as the limit is exceeded."

The formula is:

$$\text{Safe load in lbs.} = \frac{2wh}{s+1} \qquad (1)$$

in which w = the weight of hammer in pounds; h, its fall in feet; and s, the average set under the last blows in inches.

For convenience the following table is given which shows the allowable or safe bearing values for piles, calculated from the above formula, for different penetrations under the blows of a 2,000-pound hammer falling from 3 to 30 feet.

TABLE III.

Safe Load, in Tons, for Wooden Piles.

(Hammer weighing one ton.)

Penetration of Pile in Inches.	Drop of the Hammer, in Feet.												
	3	4	5	6	8	10	12	14	16	18	20	25	30
0.25	4.8	6.4	8.1	9.7	12.9	16.1	19.4	22.5	25.8	29.1	32.3	....	....
0.50	4.0	5.3	6.7	8.0	10.7	13.3	16.1	18.7	21.3	24.0	26.6	33.3	....
0.75	3.4	4.6	5.7	6.9	9.2	11.5	13.8	16.1	18.4	20.7	23.0	28.8	34.5
1.00	3.0	4.0	5.0	6.0	8.0	10.0	12.0	14.0	16.0	18 0	20.0	25.0	30.0
1.25	....	3.6	4.5	5.4	7.1	8.9	10.7	12.5	14.3	16.1	17.9	22.3	26.7
1.50	....	3.2	4.0	4.8	6.4	8.0	9.6	11.2	12.8	14.4	16.0	20.0	24.0
1.75	....	....	3.6	4.4	5.8	7.3	8.8	10.2	11.7	13.1	14.6	18.2	21.9
2.00	....	....	3.3	4.0	5.3	6.7	8.0	9.3	10.7	12.0	13.3	16.7	20.0
2.50	....	....	....	3.4	4.6	5.7	6.9	8.0	9.1	10.3	11.4	14.3	17.1
3.00	....	....	....	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.5	15.0
3.50	....	....	....	....	3.6	4.4	5.3	6.2	7.1	8.0	8.9	11.1	13.3
4.00	....	....	....	....	3.2	4.0	4.8	5.6	6.4	7.2	8.0	10.0	12.0
5.00	....	....	....	....	....	3.3	4.0	4.7	5.3	6.0	6.7	8.3	10.0
6.00	....	....	....	....	....	....	3.4	4.0	4.6	5.1	5.7	7.1	8.6

As the values in the above table vary directly with the weight of the hammer, if the penetration is caused by a 1,000-pound hammer, the bearing value will be one-half of that given, and in this way the table may be used to obtain the bearing value of piles driven by a hammer of any weight.

49. MUNICIPAL REGULATIONS REGARDING WOODEN PILES.—The New York Building Law, 1906, provides that

"Piers intended to sustain a wall, pier or post shall be spaced not more than 36 nor less than 20 inches on centers, and they shall be driven to a solid bearing, if practicable to do so, and the number of such piers shall be sufficient to support the superstructure proposed.

"No pile shall be used of less dimensions that 5 inches at the small end and 10 inches at the butt for short piles, or piles 20 feet or less in length, and 20 inches at the butt for long piles, or piles more than 20 feet in length.

"No pile shall be weighted with a load exceeding 40,000 pounds.

"The tops of all piles shall be cut off below the lowest water line. When required, concrete shall be rammed down in the interspaces between the heads of the piles to a depth and thickness of not less than 12 inches and for 1 foot in width outside of the piles."

The Boston Building Law, 1907, requires that

"All buildings shall, if the commissioner determines that piling is necessary, be constructed on foundation piles which, if of wood, shall be not more than 3 feet apart on centers in the direction of the wall, and the number, diameter and bearing of such piles shall be sufficient to support the superstructure proposed. The commissioner shall determine the grade at which the piles shall be cut.

"All wood piles shall be capped with block granite levellers, each leveller having a firm bearing on the pile or piles which it covers, or with first-class Portland cement concrete not less than 16 inches thick, above the pile caps, containing 1 part of cement to not more than 6 parts of properly graded aggregate of stone and sand, the concrete to be filled in around the pile heads upon the intervening earth."

In the Chicago Building Law, 1906, it is required that

"The piles shall be made long enough to sustain the required load according to approved formulas for pile driving, and timber piles shall not be loaded more than 25 tons to each pile."

The Philadelphia Bureau of Building Inspection stipulates that

"Piles intended for a wall, pier or post to rest upon, shall not be less than 5 inches in diameter at the small end, and shall be spaced not more than 30 inches on centers, or nearer if required by the Bureau of Building Inspection, and they shall be driven to a solid bearing. No pile shall be weighted with a load exceeding 40,000 pounds. The tops of all piles shall be cut off below the lowest water line where required; concrete shall be rammed down in the interstices between the heads of the piles to the depth and thickness of at least 12 inches, and for 1 foot in width outside of the pile. When ranging and capping timbers are laid on piles for foundations they shall be of hard wood not less than 6 inches thick, and properly joined, and their tops laid below the lowest water line."

General William Sooy Smith, in an address delivered March 31, 1892, before the students of engineering of the University of Illinois,

stated that "A pile at the bottom of a pit 30 feet deep and well into hard-pan, or to the rock where this is within reach, can be safely relied upon to sustain from 30 to 40 gross tons."

50. EXPERIMENTS ON THE BEARING POWER OF WOODEN PILES.—The following description of several tests made to determine the actual sustaining power of piles in various localities gives a good idea of the manner of making such tests, as well as of the loads required to sink the piles:

CHICAGO PUBLIC LIBRARY.—To determine the actual resistance of the piles on which it was proposed to erect the Public Library building in Chicago, the following test was made: In order to make the experiment under the same conditions as would exist under the structure three rows of piles were driven into the trench, the piles in the middle row being then cut off below the level at which those in the outside row were cut off, so as to bring the bearing only on four piles, two in each outside row. This gave the benefit arising from the consolidation of the material by the other piles. The piles were of Norway pine, 54 feet long, and were driven about 52½ feet, 27 feet in soft, plastic clay, 23 feet in tough, compact clay and 2 feet in hard-pan. They had an average diameter of 13 inches and an area at the small end of 80 square inches.

On top of the four outside piles, which were spaced 5 feet apart on centers, 15-inch steel I-beams were placed, and upon these a platform, 7 by 7 feet, composed of 12 by 12-inch yellow pine timbers. On this platform pig-iron was piled up at irregular intervals. When 4 feet high the load was 45,200 pounds, and was then continued, until at the end of about four days it was 21 feet high, giving a load of 224,500 pounds. Levels were taken, but no settlement had occurred. By the end of about eleven days the pile of iron had reached the height of 38 feet, giving a load of 404,800 pounds upon the four piles, or about 50.7 tons per pile. Levels were then taken at intervals during a period of about two weeks, and, no settlement having been observed, a load of 30 tons was considered perfectly safe.

PERTH AMBOY, N. J., 1873.—Pretty fair mud, 30 feet deep. Four piles, 12, 14, 16 and 18 inches diameter at top, 6 to 8 inches at foot, were driven in a square to depths of from 33 to 35 feet. A platform was built upon the heads of the piles and loaded with 179,200 pounds, or 44,800 pounds per pile. After a few days the loads were removed. The 18-inch pile had not moved, the 12-inch pile had settled 3 inches, and the 14 and 15-inch piles had settled to a less extent.*

BUFFALO, N. Y.—In the construction of a foundation for an elevator at Buffalo, N. Y., a pile 15 inches in diameter at the large end, driven 18 feet, bore 25 tons for twenty-seven hours without any ascertainable effect. The weight was then gradually increased until the total load on the pile was 37½ tons. Up to this weight there had been no depression of the pile, but with 37½ tons there was a gradual depression which aggregated ⅝ of an inch, beyond which there was no depression until the weight was increased to 50

* "A Practical Treatise on Foundations." W. M. Patton.

tons. With 50 tons there was a further depression of ⅞ of an inch, making the total depression 1½ inches. Then the load was increased to 75 tons, under which the total depression reached 3⅙ inches. The experiment was not carried beyond this point. The soil, in order from the top, was as follows: 2 feet of blue clay, 3 feet of gravel, 5 feet of stiff red clay, 2 feet of quicksand, 3 feet of red clay, 2 feet of gravel and sand and 3 feet of very stiff blue clay. All the time during this experiment there were three pile-drivers at work on the foundation, thus keeping up a tremor in the ground. The water from Lake Erie had free access to the pile through the gravel. *

"Subsequent use shows that 74,000 pounds is a safe load."—W. M. Patton.

PHILADELPHIA.—At Philadelphia in 1873 a pile was driven 15 feet into soft river mud, and five hours after 7.3 tons caused a sinking of a very small fraction of an inch; under 9 tons it sank ¾ of an inch and under 15 tons it sank 5 feet.

"The South Street, Philadelphia, bridge approach fell by the sinking of the foundation piles under a load of 24 tons each. They were driven to an absolute stoppage by a 1-ton hammer falling 32 feet. Their length was from 24 to 41 feet. The piles were driven through mud, tough clay, and then into hard gravel."†

The failure in this case may have been caused by vibrations which allowed the water to work its way down the sides of the piles and thus decrease the friction; or, what is more probable, the last blow may have struck on a broomed head, which would have greatly reduced the penetration and caused the bearing power to be overestimated.

When the penetration is very slight or unobservable, and the head much broomed, the broomed portion should be cut off and the blows repeated if the full load indicated by the formula is to be put on the piles.

51. ACTUAL LOADS ON WOODEN PILES.—The following examples of the actual loads which are carried by each pile under the buildings named will serve as a guide to architects erecting buildings in these localities:

BOSTON.—Under Trinity Church, 2 tons each.

CHICAGO.—Public Library building, 30 tons each.

Schiller building, estimated load 55 tons per pile; building settled from 1½ to 2¼ inches.

Passenger Station, Northern Pacific Railroad, Harrison Street: piles 50 feet long carry 25 tons each without perceptible settlement.

The enormous grain elevators in Chicago rest upon pile foundations. Mr. Adler stated that the unequal and constantly shifting loads are a severer test upon the foundations than a static load of a twenty-story building.

NEW ORLEANS.—Piles driven from 25 to 40 feet in a soft, alluvial

* "Masonry Construction." Ira O. Baker.
† Trans. Am. Soc. of C. E., Vol. VII., p. 264.

soil carry safely from 15 to 25 tons, with a factor of safety of 6 to 8.—W. M. Patton.

52. SPACING OF WOODEN PILES.—Wooden piles should be spaced not less than 2 feet on centers, nor more than 3 feet on centers, unless iron or wooden grillage is used.

When long piles are driven closer together than 2 feet on centers there is danger that they may force each other up from their solid bed on the bearing stratum. Driving the piles close together also breaks up the ground and diminishes the bearing power.

When three rows of piles are used the most satisfactory spacing is 2 feet 6 inches on centers across the trench, and 3 feet on centers longitudinally, provided this number of piles will carry the weight of the building. If they will not, then the piles must be spaced closer together longitudinally, or another row of piles driven; but in no case should two piles be driven closer together than 2 feet on centers, unless driven by means of a water-jet.

In all cases, the number of piles under the different portions of a building should be carefully proportioned to the weight which they have to carry, so that every pile will support very nearly the same load. This precaution is of especial importance when some of the piles must be loaded to their full capacity.

53. CUTTING OFF AND CAPPING WOODEN PILES.—The tops of the piles should invariably be cut off below the low-water mark, as otherwise they will soon commence to decay.

The piles are generally cut off with a large cross-cut saw worked by two men. Their tops should be left true and level and on a line with each other. A variation of ½ of an inch in the tops of the piles may be allowed, but it should not exceed this limit.

Three methods of capping wooden piles are commonly employed, using the following materials: 1. Granite blocks. 2. Concrete. 3. Timber or steel-beam grillage.

54. GRANITE CAPPING FOR WOODEN PILES.—In this method the piles are capped with blocks of granite, which rest directly on the tops of the piles. If the stone does not fit the surface of a pile, or a pile is a little low, it is wedged up with oak or stone wedges. In capping with stone a section of the foundation should be laid out on the drawings showing the arrangement of the capping stones.

A single stone may rest on one, two or three piles, but should *not* rest on four piles, as it is practically impossible to make the stone

bear evenly on four piles. Fig. 14 shows the best arrangement of the capping for three rows of piles. Under dwellings and light buildings the piles are often spaced as in Fig. 15, in which case each stone should rest on three piles. After the piles are capped large footing stones, extending in one piece across the wall, should be laid in cement mortar, as shown in Fig .16.

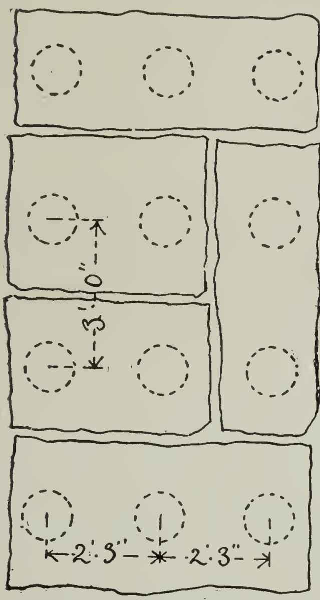


Fig. 14. Stone Capping for Three Rows of Piles.

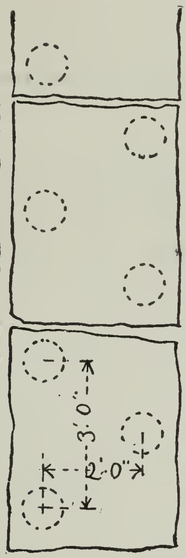


Fig. 15. Stone Capping for Piles Under Light Buildings.

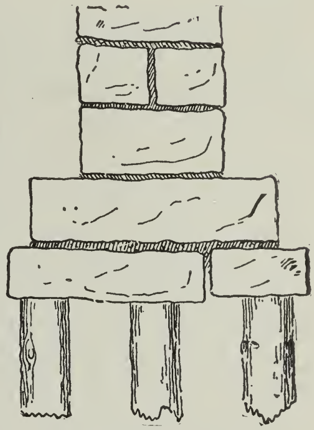


Fig. 16. Stone Capping and Wall Footing on Piles.

55. CONCRETE CAPPING FOR WOODEN PILES.—In New York a very common method of capping the piles is to excavate to a depth of 1 foot below the tops of the piles and 1 foot outside of them, and to fill solid the space thus excavated with rich Portland cement concrete, deposited in layers and well rammed. After the concrete is brought up level with the tops of the piles, additional layers of concrete are laid over the whole foundation until it reaches a depth of 18 inches above the piles. On this foundation bed, the brick or stone footings are laid as on solid earth. Many engineers consider this the best method of capping. There is certainly no question of its durability, and it is believed that the concrete will preserve the heads of the piles from rotting, provided the water is at

all times up to the bottom of the concrete. A concrete beam 18 inches thick would also serve to distribute the pressure over the piles better than the stone capping, although not to such an extent as heavy grillage. If the soil is at all firm under the concrete, it will also assist the piles in carrying the load when concrete capping is used. Under very heavy buildings the space between the piles to the depth of 1 foot should be filled with concrete, whatever kind of capping is employed.

Concrete cappings in which steel rods or bars are imbedded about 3 inches above the tops of the piles are excellent forms of capping construction, the metal bars giving great transverse strength to the concrete.

56. GRILLAGE CAPPING FOR WOODEN PILES.—In Chicago most of the buildings on pile foundations have heavy timber grillage bolted to the tops of the piles, and on these timbers are laid the stone or concrete footings. For building foundations the grillage usually consists of 12 by 12-inch timbers of the strongest woods available, laid longitudinally on top of the piles, and fastened to them by means of *drift-bolts,* which are plain bars of iron, either round or square, driven into holes about 20 per cent smaller in cross-section than that of a bolt. One-inch round or square bars are generally used, each hole being bored by a ¾-inch auger for a round bolt, or by a ⅞-inch auger for a square bolt. The bolts should enter the piles at least 1 foot.

If heavy stone or concrete footings are used, and if the space between the piles and the timbers is filled with concrete brought up level with the top of the timbers, no more timbering is required; but if the footings are made of small stones, and if no concrete is used, a solid floor of cross timbers, at least 6 inches thick for heavy buildings, should be laid on top of the longitudinal cappings and drift-bolted to them.

Where timber grillage is used, it should, of course, be kept entirely below the lowest recorded water line, as otherwise it will rot and allow the building to settle. It has been proved conclusively, however, that any kind of sound timber will last practically forever if completely immersed in water.

The advantages of timber grillage are that the timbers are easily laid and effectually hold the tops of the piles in place. It also tends to distribute the pressure evenly over the piles, as the transverse

strength of the timber assists in carrying the load over any single pile, which for some reason may not have the same bearing capacity as the others.

Steel-Beam Grillage for Wooden Piles.—Steel beams, imbedded in concrete, are sometimes used to distribute the weight over piles, but some other form of construction can generally be employed at less expense and with equally good results.

57. COST OF WOODEN PILES.—The cost of wooden piles varies with the locality, size of piles and difficulties encountered in driving. Wooden piles of good quality and average size, say 10 inches average diameter and from 15 to 25 feet in length, can be driven for from 20 to 25 cents per foot of length, this price including the cost of the timber and driving. The variation from these prices may be as much as 25 per cent either way, and where only a few piles are to be driven, the cost will greatly exceed the maximum here given.

B. CONCRETE PILES

58. CONCRETE PILES COMPARED WITH WOODEN PILES AND CONCRETE PIERS.—Piles made of concrete have been used in this country since 1902, and they offer several advantages over wooden piles. They remain practically uninjured after the operation of driving, they do not decay, and it is not necessary to keep them constantly under water to preserve them, as it is in the case of wooden piles. Consequently, concrete piles can be often used to advantage in place of wooden piles, and frequently may be put in at a lower cost than that of spread-footing construction. They do not, as a rule, require as thick a capping as that required for wooden piles, because they are more readily incorporated with the concrete or masonry of the capping, and not so many of them are required, because they sustain a greater load than wooden piles bear, under similar conditions.

In Fig. 17 a comparison is drawn between the method of using concrete piles and the method of penetrating a soft soil by means of wooden sheet piling and a concrete pier. It is frequently found in cases of this kind that the concrete piles are cheaper than the concrete pier.

Another illustration showing some of the advantages gained by the use of concrete piles is given in Fig. 18, (a) and (b). In figure (b) the wooden piles are shown driven deep enough to be below the

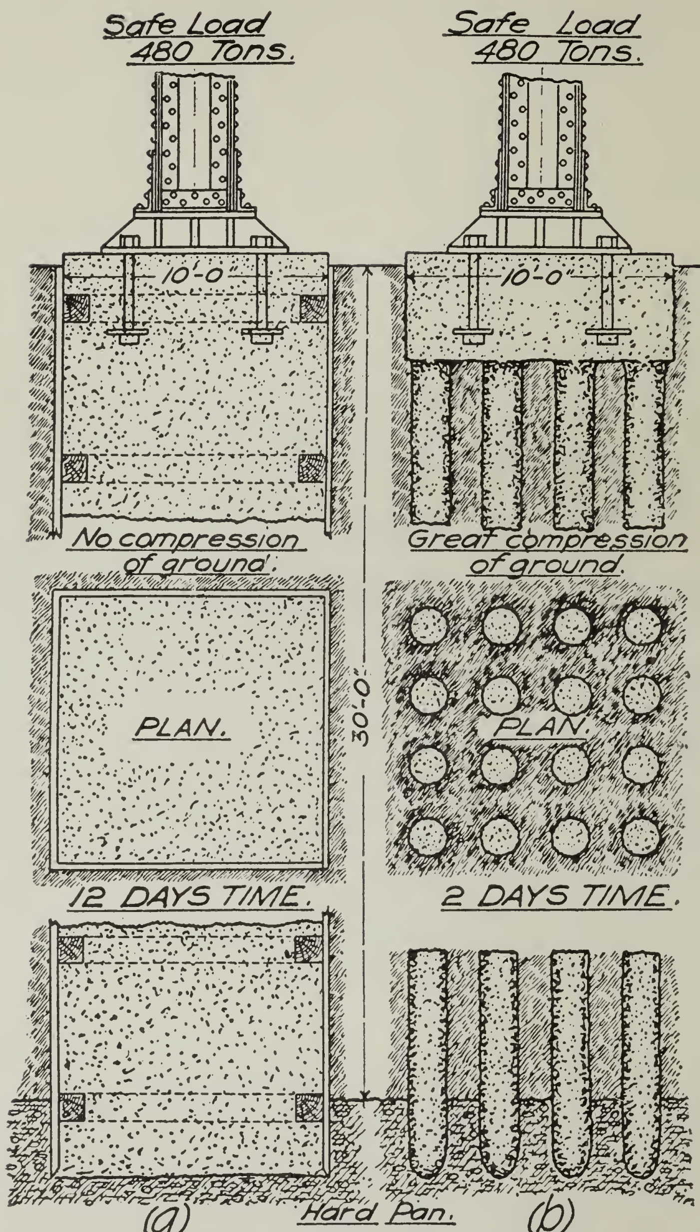


Fig. 17. Concrete Piles and Concrete Piers Compared.

low-water level. This necessitates a deep foundation wall; and as the wooden piles will not sustain as great a load as the concrete piles, a greater number of them is required, with a correspondingly ex-

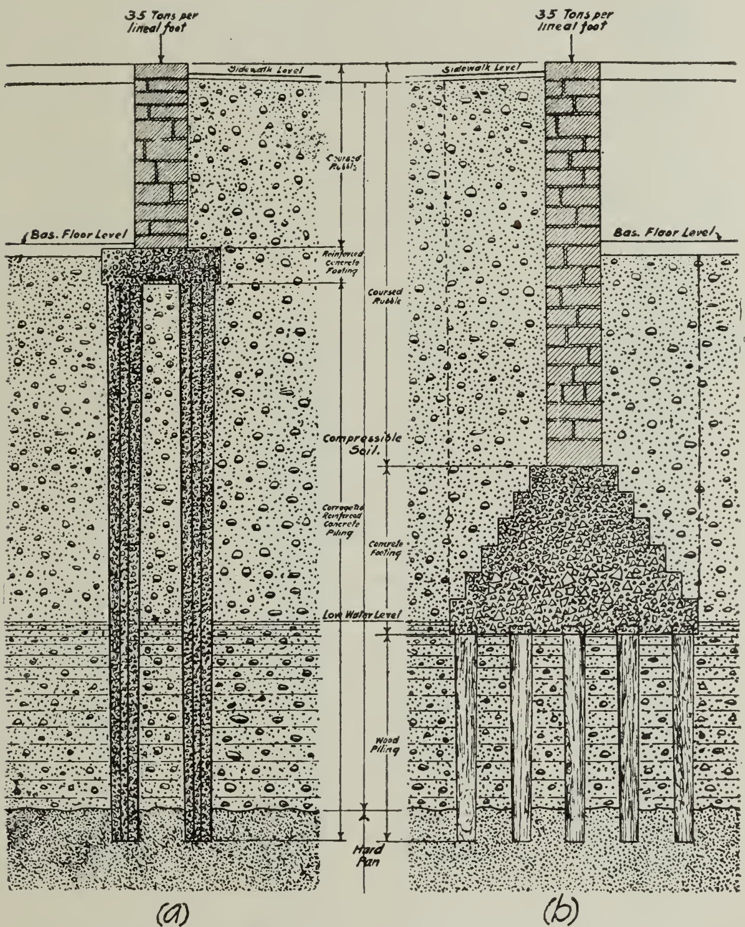


Fig. 18. Concrete Piles and Wooden Piles Compared.

tended footing. Figure (a) shows the foundation of the same building constructed on concrete piles with much less excavating, and with probably greater permanency.

Several types of concrete piles are used, varying in details of construction and in manner of driving, and among them may be mentioned the "Raymond," the "Simplex" and the "Corrugated."

59. THE RAYMOND CONCRETE PILE.—This concrete pile is made by driving a collapsible steel core, around which is a sectional tank-steel shell, the sections being conical, and fitting closely one within the other. When this core with its outside shell has been driven to the required depth, the core is partially collapsed, released from the sectional steel shell, and withdrawn. In this manner a sheet-steel-lined form or mold is made in the ground for casting the pile, the lining acting in the same manner as a caisson in holding back the earth, and in preventing the partial filling of the form by loose particles, or its destruction by any pressure on the surrounding soft stratum. After the mold is thus formed it is filled with a good mixture of concrete, which is carefully tamped during the process of filling.

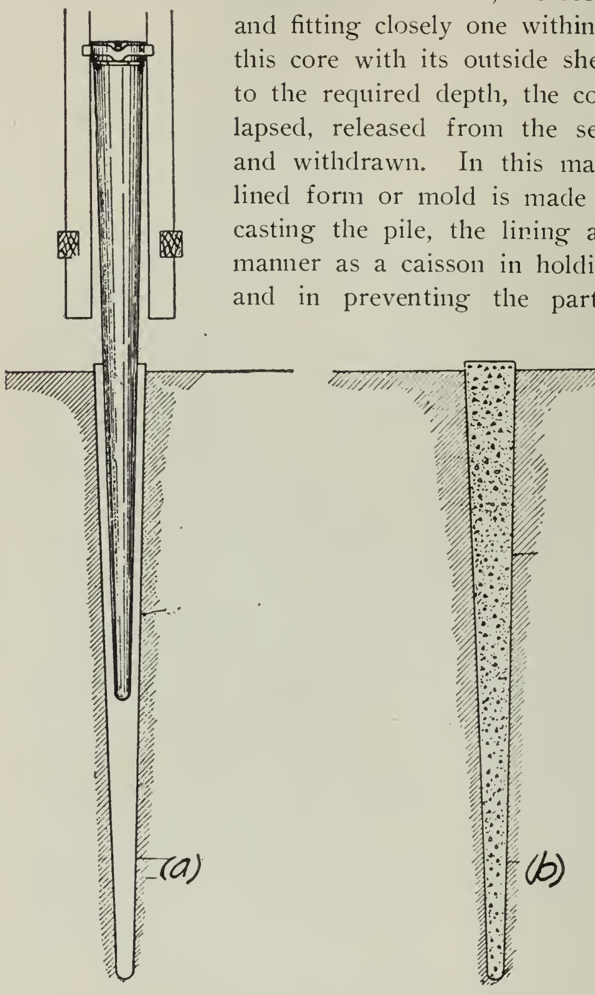


Fig. 19. The Raymond Concrete Pile.

Sometimes these piles are reinforced to increase their strength, or to provide anchorage for stacks or tower foundations subjected to

wind-pressure. Such reinforcement is easily put in place during the process of filling. The form of the "Raymond" concrete pile and a diagrammatical representation of the method of driving the cone and shell is shown in Fig. 19, (a) and (b).

60. THE SIMPLEX CONCRETE PILE.—This concrete pile,

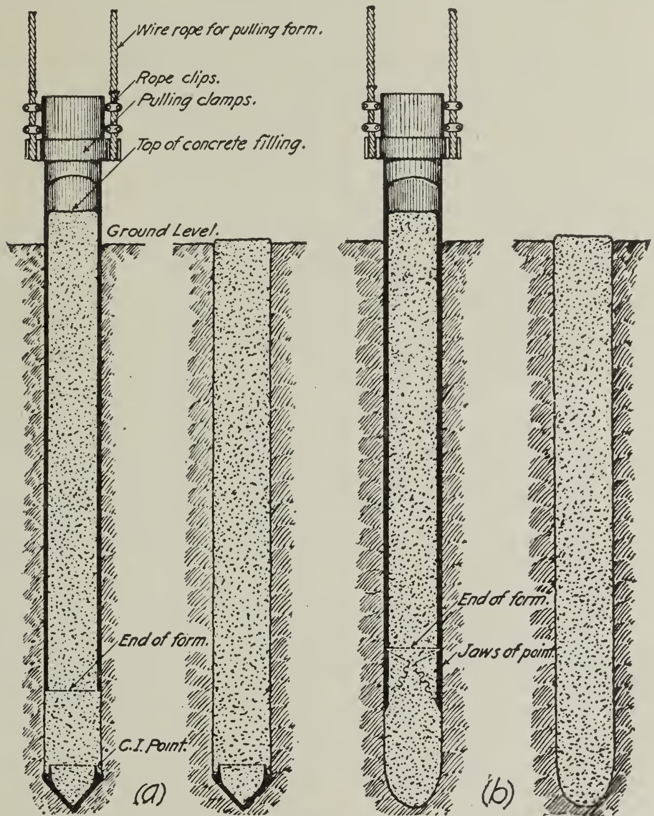


Fig. 20. The Simplex Concrete Pile.

like the "Raymond," is made in the ground and not driven. The form of the pile differs from the "Raymond," the sides being parallel instead of tapering, and when finished there is no surrounding steel cylinder.

The construction of the "Simplex" pile is shown in Fig. 20, (a) and (b). At (a) is shown an extra heavy steel pipe about 16 inches in diameter, driven into the ground. At the end of the pipe there is a penetration-shoe of cast-iron used to prevent the earth from

filling the pipe while it is being driven. When the steel cylinder reaches the required depth and rests upon hard-pan or penetrates hard gravel, it is filled with concrete as the steel driving form is partly withdrawn, and the penetration-shoe is released and left in the ground. The weight of the concrete causes it to flow out at the lower end of the pipe or driving form and completely fill the hole in the soil.

A second method of forming the pile consists in providing an "alligator-jaw" or hinged point at the end of the cylinder, instead of a cast-iron penetration-shoe. This is shown at (b). This jaw is opened to the full extent of the form when the cylinder is withdrawn, allowing the concrete to flow into the hole.

As the hole formed by the pipe is not lined with sheet-metal there is a possibility of some soft earth pressing in upon the concrete before it has set, thus preventing a uniformity of cross-sections. This has not proved a serious trouble, however.

Concrete piles are sometimes used in conjunction with timber piles, and when so employed are called "composite piles." These piles are used for driving to a great depth in comparatively soft soil. The concrete pile caps the timber pile and forms an extension to it from below the low-water line, and it is said to afford a cheaper construction under some conditions than longer piles made entirely of concrete.

61. THE CORRUGATED CONCRETE PILE.—There are several reinforced concrete piles in use, which are first molded to the required shape, and when the concrete has set sufficiently, are driven by a hammer, a water-jet, or a combination of both methods, in much the same manner as wooden piles are driven, about the only difference being the special "driving head" provided to avoid the shock of the hammer.

A section through what is known as the "Corrugated Concrete Pile" is shown in Fig. 21. This particular form of concrete pile is made with a vertically corrugated surface, and with a hole left vertically through the axis of the pile. It is driven by using the water-jet and hammer together. A hose, or pipe, with water under pressure, is passed down through the hole in the middle of the pile while it is in the machine.

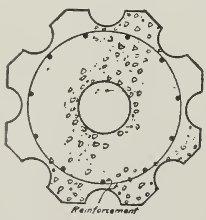


Fig. 21, The Corrugated Concrete Pile.

The force of the water at the lower end loosens the earth and drives it up along the corrugations, and the pile settles under the blows of the hammer on its cushioned head. In one instance it was found that after the concrete had had eight days to set, the piles were not damaged in any way at their upper ends by the action of the hammer.

These corrugated concrete piles are reinforced with "Clinton" electrically welded wire fabric, consisting generally of ⅜ inch wires, 3 inches on centers longitudinally, and ⅛ inch wires 12 inch on centers around the pile.

62. THE COMPRESSOL SYSTEM.—There is another kind of construction which may be classified with the other types of concrete pile construction, and that is the "Compressol System of Foundation Construction." In this system the ground is mechanically perforated by dropping a pointed weight very similar in form to an enlarged plumb-bob. This pointed weight, dropped rapidly, perforates the ground and compresses it vertically and laterally, and the hole so formed is filled with concrete. The latter is thoroughly tamped, and forms a pillar strong enough to carry from 60 to 90 tons, according to the nature and depth of the soil. The piers of concrete so formed are capped with concrete in a manner similar to that of capping concrete piles.

The method used in constructing these piers or cores in the earth is shown in Fig. 22. The weight drops and perforates the soil, the hole usually going down to hard-pan. The falling of the weight compresses the soil on each side of the hole and prevents the percolation of water into it. Sometimes the hole can be lined with puddle or clay by inserting some of this material under the perforating hammer and allowing it to be carried down to line the hole. When the ground has been perforated as described, a coarse concrete is tamped into the bottom of the hole, and a hammer shaped as shown in the figure is dropped, striking successive blows as the hole is filled. In this manner the concrete is forced and tamped compactly into the hole, and spread out at the bottom as indicated in the figure at (b); so that if the earth were excavated from around the concrete pier, the latter would appear as shown in Fig. 23.

The following are some of the advantages claimed for this system of foundation construction: Pillars of concrete can be formed to

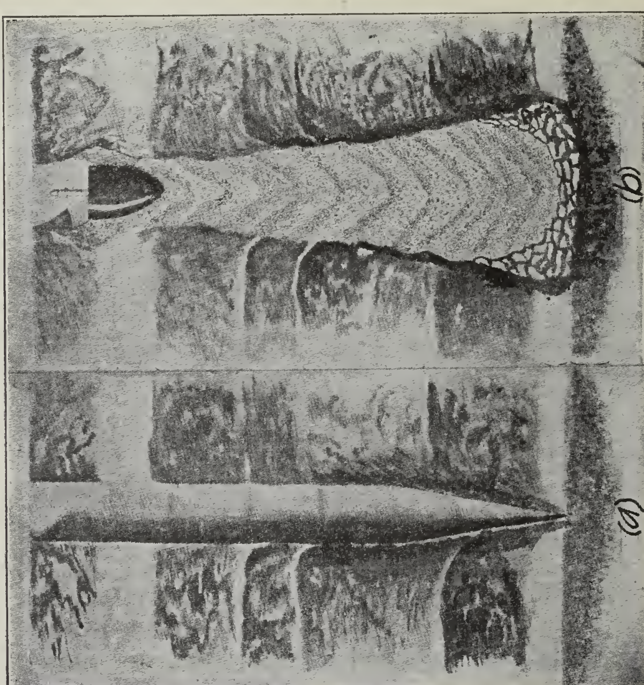


Fig. 22. The Compressol System of Concrete Foundation.

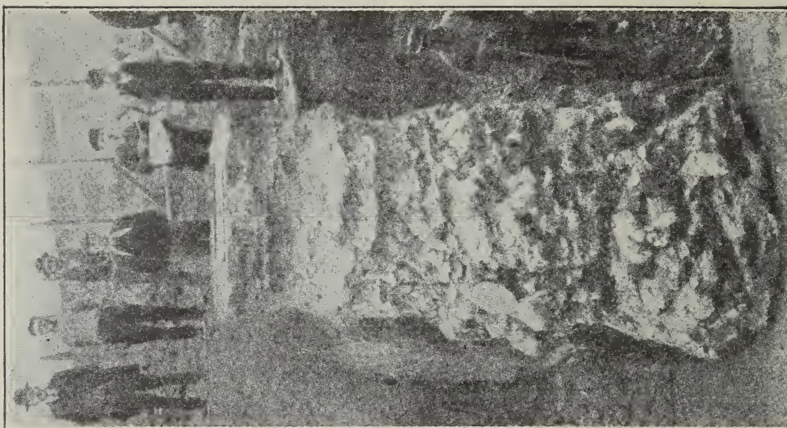


Fig. 23. Concrete Pier, Compressol System.

a depth of 50 feet in marshy soils, and even in quicksand; the system is economical, as it requires no outlay for excavation, sheet-piling, pumping, etc.; the work goes on with considerable rapidity, because a pillar strong enough to support 90 tons with safety can be constructed, under favorable conditions, in 4 hours; the dangers to the workmen in caisson construction are eliminated; and from the amount of penetration of the conical weight or hammer, the bearing strength of the strata adjacent to the pillars may be approximately determined. An elevation and a cross-section, illustrating

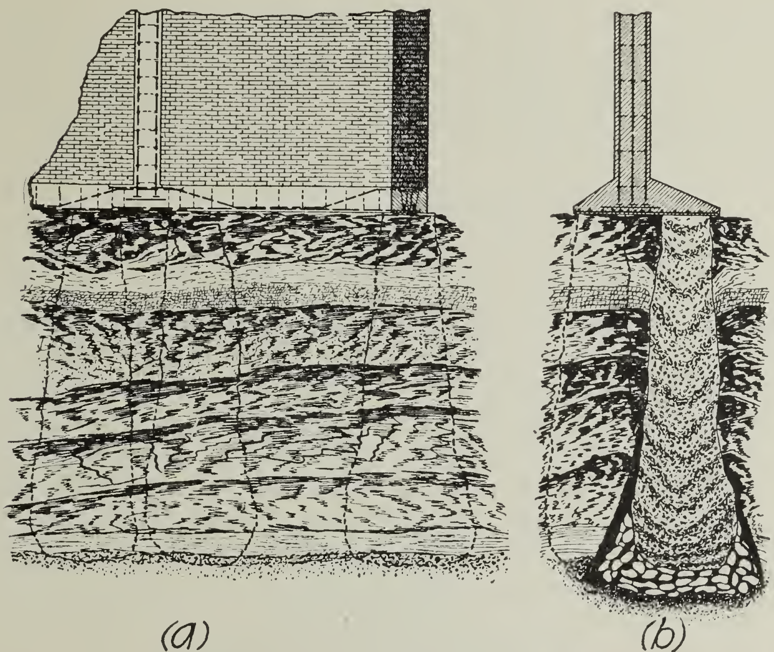


Fig. 24. The Compressol System of Concrete Foundation.

the use of the Compressol system of foundation construction for a building erected upon soft or unstable soil, are shown in Fig. 24, in which (a) is a side view of an exterior wall, with reinforced concrete lintels bearing upon the top of the Compressol foundations, supporting their load of brick-work and resting upon the concrete wall piers; and (b) is the same kind of construction supporting an interior column.

63. COST OF CONCRETE PILES.—The cost of concrete

piles is much greater than that of timber piles, but as their bearing strength is on an average twice as great, and as greater dependence may be placed upon them, the number of piles, and consequently the total cost, may be reduced.

Prices have been quoted for "Simplex" concrete piles at Salem, Mass. The number of piles was 203 and the length fixed at an average of 17 feet with a total minimum length of 2,000 linear feet. The base price quoted was $1.46 per foot, additional lengths being charged for at 90 cents per foot. For lengths shorter than 17 feet, a deduction was allowed at 90 cents per foot.

These piles were 16 inches in diameter and were made of 1 part of Portland cement, 2½ parts of sand, and 5 parts of broken and crushed stone. The prices represent a fair average cost of concrete pile construction for a moderate number of piles cast in the ground under average conditions.

2. SPREAD FOUNDATIONS

64. SPREAD FOUNDATIONS IN GENERAL.—Compressible soils are often met with which will bear from 1 to 2 tons per square foot with very little settlement, and, as a rule, this settlement is uniform under the same *unit-pressure*. When unit-pressure is referred to in connection with foundation soils, the pressure per square foot of bearing surface is usually understood. In such cases it is often cheaper to spread the foundations so as to reduce the unit-pressure to the capacity of the soil than to attempt to drive piles or to use sheet-piles with extensive excavations through soft and wet soils. "Spread" footings may be built of reinforced concrete, consisting of concrete with iron or steel tension-bars imbedded therein, of steel beams and concrete, or of timber and concrete.

A. REINFORCED CONCRETE FOOTINGS

65. GENERAL DESIGN.—One of the most efficient and economical methods of constructing spread footings is that of reinforced concrete, consisting of beds or layers of concrete to which additional resistance to transverse stresses is added by embedding in the concrete, steel or iron rods or bars placed near the bottom surfaces of the footings, where the tensile stresses are developed. This metal reinforcement consists of plain, round, square, or twisted bars, or of expanded-metal, woven wire, or any of the special patented bars, known as "deformed bars," now on the market.

When a footing is constructed, as shown in Fig. 25, at (a), so that a line drawn at an angle of 60° with the horizontal will intersect both the lower outside edges of the footing and of the wall, or of the solid base bearing upon the footing, there is little danger of the failure of the footing from bending stresses, whereas there would be danger of such failure if the footing had a considerable

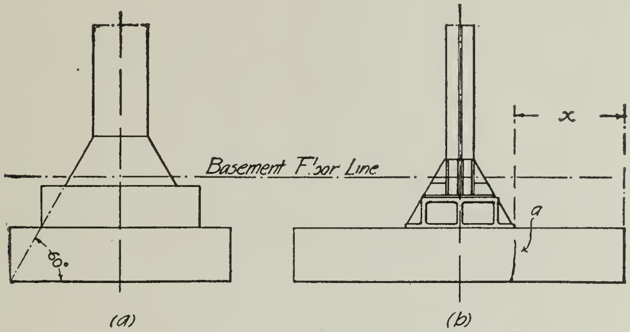


Fig. 25. Footings with Small and Large Projections.

projection, as shown in the figure at (b). In the latter illustration the projection x may be great enough to result in causing the upward pressure on it from the soil to bend it upward and to cause its failure by stresses developed by flexure, as shown by the fracture at g. This principle of construction is further treated in Chapter III.

66. WALL AND COLUMN FOOTINGS.—Reinforced con-

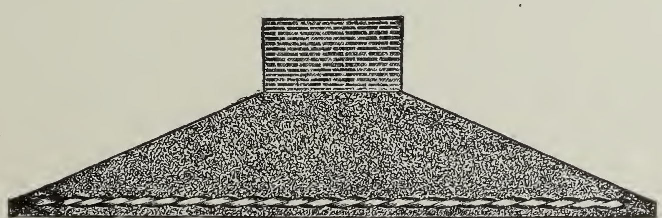


Fig. 26. Concrete Footing with Twisted Reinforcement.

crete spread footings may be used for walls or for piers or columns. Fig. 26 shows the most economical section for a concrete and twisted iron footing. In building the footings with steel beams, the strength of the concrete is practically wasted, while in this method of construction it is all utilized. A large percentage of the tensile strength of the twisted bars can be utilized, and, being held

continuously along their entire length by the concrete as a screw bolt is held by the nut, they neither draw nor stretch, except as the concrete extends with them.

Fig. 27 shows a typical spread footing for a heavy wall, resting upon soil of a soft and unreliable nature. Here the bottom of the footing is reinforced with the steel rods, *a*, to prevent a failure of the projection of this footing by transverse or bending stresses. Above the spread footing a deep course of concrete is provided with reinforcing rods or bars, *b*, extending longitudinally or lengthwise of the wall, so so that if the soil is softer in some places than in others, the heavy upper course of concrete will have sufficient strength to span the weak places and thus prevent unequal settlements and unsightly cracks in the walls.

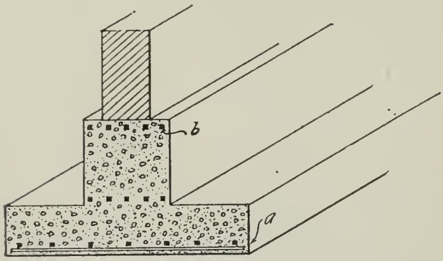


Fig. 27. Typical Reinforced Concrete Footing for Heavy Wall.

A typical design for a reinforced concrete column footing is shown in Fig. 28. In this illustration the structural steel column *a* is provided with a heavy structural steel base, designed to transmit the load sustained by the column to the top bed of the concrete footing. The spread footing of reinforced concrete, *c*, has another block of concrete, *b*, above it, to lessen the projection of the bottom course. The latter is reinforced with a double layer of rods or bars crossing each other at right angles. As the load ordinarily transmitted by the columns to the reinforced concrete footing is considerable, it is considered good practice to provide, under the bearing-plate of the column, a "mattress" consisting of two layers of reinforcing rods, as shown at *d*. These rods reinforce the concrete directly beneath the bottom or bearing-plate of the column, and the base is usually proportioned with an area which stresses the concrete up to 500 pounds per square inch. This is the allowable stress for reinforced concrete, adopted by several cities in the compilation of their building laws.

In very large and heavily loaded spread column footings it is sometimes necessary to provide vertical reinforcement throughout the body of the footing by introducing stirrups extending up into the

body of concrete, so as to provide sufficient bond between the several actual or theoretical layers of the concrete to prevent them from

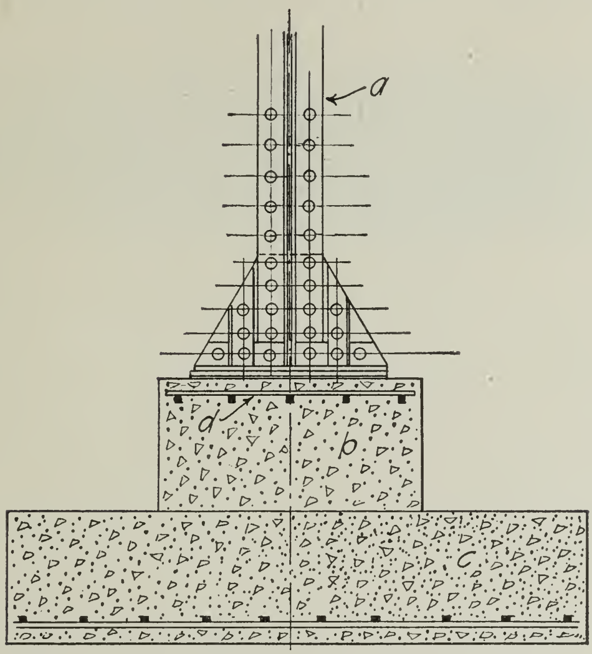


Fig. 28. Typical Reinforced Concrete Footing for Column.

slipping one upon the other when they are subjected to transverse stress. An excellent construction for such a column footing is shown in Fig. 29. In this footing the reinforcement consists of two layers of what is known as the "Kahn" trussed bar, shown in detail in Fig. 30. In this construction the prongs are partially sheared from the fin of the bar and bent obliquely upward, forming stirrups, which, besides furnishing additional bond for the reinforcing rods, provide against any possible failure from the horizontal shear between the layers of the concrete. Other deformed bars may be used for spread footing reinforcement, and when stirrups or

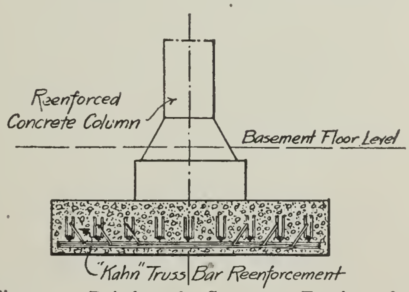


Fig. 29. Reinforced Concrete Footing for Heavily Loaded Column.

members to resist horizontal shear are required, they may be made U-form, from ⅜-inch round bar, or from ⅛ by 1 inch flat bar, wired or otherwise secured to the main reinforcing bars or rods.

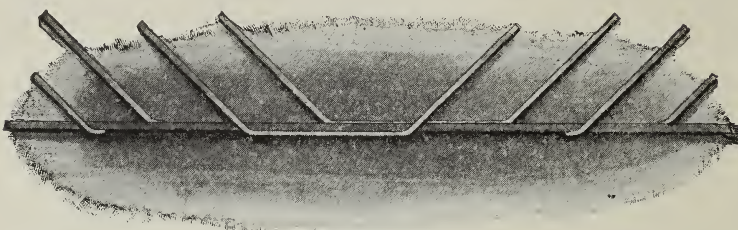


Fig. 30. Kahn Trussed Bar. Detail.

67. PLACING THE CONCRETE.—In building concrete footings, a layer of concrete from 3 to 6 inches thick, made in the proportion of 1, 2 and 4, should first be laid, and the iron bars laid on and tamped down into it. Another layer of 4 inches, mixed in the same proportions, should then be laid, after which the concrete may be mixed in the proportions of 1, 2½ and 5. Each layer should be laid before the preceding layer has had time to harden; otherwise they may not adhere thoroughly.

68. STRENGTH OF REINFORCED CONCRETE FOOTINGS.—In order that reinforced concrete footings may be safely constructed it is necessary to determine the area and spacing of the reinforcing bars or rods at the bottom of the footings, and also to determine whether the concrete in the upper part of the footing has sufficient compressive resistance.

It is usual in designing such footings, after the bearing area has been determined by dividing the load upon them by the safe unit bearing value of the soil, to assume or decide upon their thickness, so that the amount of steel reinforcement required may be found.

In Fig. 31, (a), there is represented diagrammatically a reinforced concrete spread column footing. The distance x in the figure represents the projection of the footing beyond the edge of the column base, where the footing tends to fail by flexural stresses, because the greatest bending moment is at that point. The upward pressure of the soil upon this projection is represented by the forces w, w, w, etc., and their sum by W acting at their center of gravity. The distance of this resultant force W from the edge of the column base is the lever arm with which this force tends to bend the footing

around the edge of the column, and is equal to ½ x. The depth of the footing, or its thickness, is represented by t_1, but the theoretical depth for the purposes of calculation is the distance from the middle of the metal reinforcement to the top of the concrete.

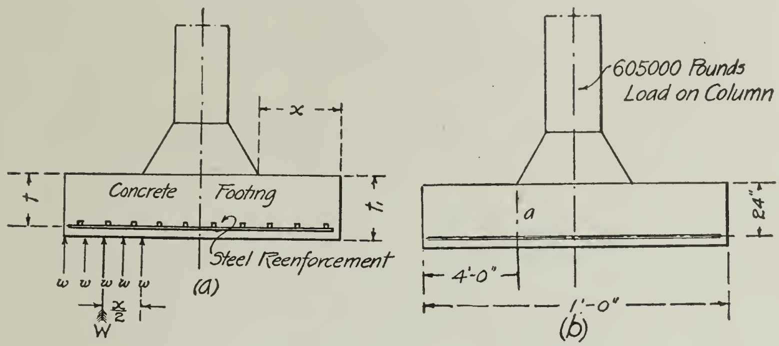


Fig. 31. Reinforced Concrete Column Footing.

In order to determine the amount of steel reinforcement in a spread footing of reinforced concrete, the following formula may be used, which is calculated to give economical, and at the same time, safe results:

$$a = \frac{W \times x}{27000 \times t} \qquad (2)$$

In this formula W is equal to the upward pressure of the soil, in pounds, on a strip of the projection of the footing one-foot in width; x is the projection of the footing beyond the edge of the column base, in inches; t is the distance from the top of the concrete footing to the middle of the steel reinforcement, also in inches; while the term 27,000 is a constant deduced from the usual formula for reinforced beams of rectangular section, and is based upon a safe unit tensile stress for steel of about 16,000 pounds per square inch. The value a, to be determined by applying this formula, is the area in square inches required for the steel reinforcement for each lineal foot in width of the footing.

Besides finding whether there is sufficient steel reinforcement in the footing by determining its area by the above formula, it is necessary to ascertain if the concrete in the upper part of the footing is over-stressed by the compressive forces caused by the bending. The maximum safe compressive stress allowed on reinforced concrete in

conservative engineering practice is 500 pounds per square inch ordinarily, and this stress should not be exceeded. To determine the maximum compressive stress on the concrete of the upper part of a reinforced concrete spread footing, the following formula may be used:

$$c = \frac{W \times x}{4.59 \times t^2} \qquad (3)$$

In this formula W, x and t represent the same values as given for the foregoing formulas, the constant being 4.59. The value c is the compressive stress in pounds per square inch near the upper surface of the concrete footing at the edge of the column base.

These two formulas (2) and (3) are sufficiently correct for all practical purposes and are based on the latest information derived from tests on reinforced concrete beams of rectangular section. They may be expressed by the following rules:

Rule 1.—To find the area of steel, in square inches, required for each lineal foot in width of a reinforced concrete footing: divide the product of the upward pressure in pounds on the projection of the footing one foot in width and the length of the projection of the footing in inches, by 27,000 multiplied by the distance in inches from the middle of the steel reinforcement to the top surface of the concrete footing.

Rule 2.—To find the amount of maximum compressive stress per square inch upon the concrete adjacent to the top surface of the concrete footing: divide the product of the upward pressure in pounds on the projection of the footing one foot in width and the length of the projection in inches, by 4.59, multiplied by the square of the distance from middle of the steel reinforcement to the top surface of the concrete footing.

Example.—A reinforced column footing of the design shown in Fig. 31, (*b*), is subjected to a load from the supported column of 605,000 pounds, and it is desired to determine what amount of steel will be required to reinforce this footing, and also whether the safe compressive stress in the concrete at the point *a* is exceeded.

Solution.—The area of the footing is 11 by 11 feet, or 121 square feet; so that if the total load on the footing is 605,000 pounds, the load per square foot upon the soil beneath the footing is 605,000 pounds ÷ 121, or 5,000 pounds.

The projection of the footing measured by the distance x is 4 feet; so that the total upward pressure on a portion of the footing one foot in width is 5,000 pounds x 4, or 20,000 pounds.

Since t, or the distance from the steel reinforcement to the top surface of the concrete footing, is 24 inches, all of the terms of the second member of formula (2) are known, and the sectional area of steel required for each foot in width of the footing is found as follows:

$$a = \frac{20{,}000 \times 48}{27{,}000 \times 24} = 1.49 \text{ sq. ins.}$$

The section area of a ⅞-inch square twisted bar is about .76 square inches, so that if these bars are spaced 6 inches from center to center, each foot in width of the footing will contain two bars having a total area of 1.52 square inches.

Having found the amount of the steel reinforcement for the footing, it is necessary to determine whether the concrete of the footing is over-stressed by compression. Formula (3) is used to find the value of c, which must not exceed 500 pounds per square inch. Substituting in the formula,

$$c = \frac{20{,}000 \times 48}{4.59 \times 24 \times 24} = 363 \text{ pounds per sq. in.}$$

From the result of the above calculation it is observed that the value c of 363 pounds per square inch is well within the limit of 500 pounds per square inch, so that the footing as designed may be considered as amply safe; or the thickness may be decreased, though the saving in concrete will in all probability be less than the additional cost of the steel required for the reinforcement due to the decreased distance t.*

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* These formulas, (2) and (3), are based upon tests made on reinforced concrete beams, and upon formulas derived from these tests, by Professor A. N. Talbot, of the University of Illinois. In this derivation, consider that the moment-arm for the couple formed by the tension in the steel and the compression in the concrete is 0.87. This is an average value for reinforcement under 1 per cent. Equating the bending moment to the resisting moment gives:

$$M = \tfrac{1}{2} W x = 0.87 \, a f t$$

Comparing this with formula (2), f is seen to be about 15,5000 pounds per square inch.

In dealing with the compression, consider that the neutral axis is 0.42 t below the top surface, and use the straight line relation. Equating the bending moment and the resisting moment and solving for c gives:

$$c = \frac{W x}{4.5 \, t^2}$$

Professor Talbot states that "it must be borne in mind that footings will be very short beams, and that for short beams diagonal tension failures, or so-called shearing failures are likely to result. The vertical shearing stress will then be the controlling feature of

69. TABLE OF STRENGTH AND PROPORTIONS OF FOOTINGS.—The author has prepared Table IV, giving the strength and proportions of reinforced concrete footings, which he believes have a large margin of safety. While the values given in this table vary slightly from the results obtained from the preceding formulas, the variations are on the side of safety, the values giving an excess of steel without overstressing the concrete to a great extent. In the table two sizes of bars are given, with the corresponding safe loads for the footings, the other measurements applying to both cases. The measurements in the third column refer to the width of the brick or stone footing resting on the concrete. The greater the width of this footing in proportion to the width of the concrete, the less will be the stress in the tension rods.

TABLE IV.

PROPORTIONS AND STRENGTH OF CONCRETE FOOTINGS WITH TWISTED IRON TENSION BARS.

WIDTH OF FOOTING IN FEET.	THICKNESS OF CONCRETE.		WIDTH OF STONE FOOTING.		DISTANCE BETWEEN CENTRES OF BARS.	SIZE OF SQUARE BAR.	SAFE LOAD PER LINEAL FOOT.	SIZE OF SQUARE BAR.	SAFE LOAD PER LINEAL FOOT.
	Ft.	In.	Ft.	In.	Inches.	Inches.	Tons.	Inches.	Tons.
20	3	6	6	0	8	2	78	$1\frac{7}{8}$	66
18	3	3	5	6	8	2	76	$1\frac{3}{4}$	56
16	2	10	5	0	7	$1\frac{3}{4}$	73	$1\frac{1}{2}$	50
14	2	8	4	8	7	$1\frac{5}{8}$	70	$1\frac{3}{8}$	49
12	2	6	4	4	6	$1\frac{3}{8}$	65	$1\frac{1}{4}$	48
10	2	3	4	0	6	$1\frac{1}{4}$	65	1	42
8	2	0	4	0	6	1	60	$\frac{3}{4}$	40
6	1	8	3	6	6	$\frac{3}{4}$	55	$\frac{1}{2}$	29

70. SQUARE TWISTED BARS FOR REINFORCEMENT.—For some years the use of square twisted bars for reinforcing con-

the strength of the footing unless some form of web reinforcement is used to overcome this defect. The ordinary designer will be likely to overlook this feature. The working stress for the vertical shear for short beams without efficient web reinforcement should not run more than from 30 to 50 pounds per square inch. Beams with poor concrete fail with values as low as 60 pounds per square inch, and the best ordinary concrete does not run more than 125 pounds per square inch.

"Bond stresses may control the footing, and not more than from 50 to 75 pounds to the square inch of surface should be allowed for plain bars. In the case of bars bent up, the bond stress may become the controlling element. It should be noted also that where 'bending-up' is practiced, the bend should begin at the offset. It may also be suggested that stepped or sloped effects will be of advantage in overcoming the difficulties involved in high shearing stresses."

In regard to the *form* of formulas (2)and (3), and to their "mathematical dimensions," the latter will be found to be correct, when the formulas from which they are derived are borne in mind; and the correct resulting dimensions will be given to the 27,000 and to the 4.59 appearaing in the denominators of the second members of the equations.

crete was protected by the patents of Ernest L. Ransome, of San Francisco, Cal., and subsequently by the rights owned by the Ransome & Smith Co., of New York, Chicago and San Francisco.

All patents relating to the use of square twisted bars for reinforced concrete construction have now expired, and many firms are manufacturing this type of reinforcing bar by both cold and hot twisting. They are now very generally used in reinforced concrete construction.

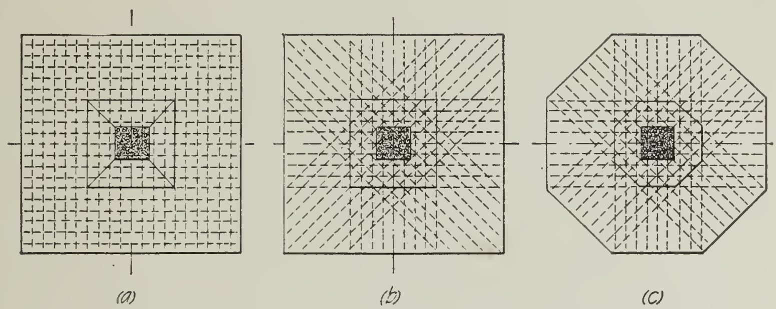

Fig. 32. Different Arrangements of Rods in Reinforced Concrete Footings.

71. PLACING THE RODS IN SPREAD FOOTINGS.—There are several ways of arranging rods in reinforced concrete column footings, some of which are shown in Fig. 32 at (a), (b), and (c). The method shown in the figure at (a) is the one commonly used and consists of two layers of reinforcing rods placed at right angles to each other and spaced an equal distance apart from center to center. Where great economy is required every alternate rod may be shortened somewhat, because the bending moment in the footing becomes smaller toward the outer edge, where it is zero, and consequently less reinforcement is required there.

The best practice in the design of reinforced concrete column footings consists in placing several layers of rods, some at right angles with each other and some diagonally, as shown in the figure at (b).

Sometimes an effort is made to save concrete by making the footing octagonal in plan, as shown at (c), as the corners of a square footing are considered relatively weak, and hence properly omitted. Where, however, they are reinforced as in the figure at (b), they are about as effective as any portion of the area of the footing, as far as the distribution of the pressure on the soil is concerned.

B. STEEL BEAM FOOTINGS

72. GENERAL DESIGN.—When it is necessary to spread the foundations over 12 or 15 feet in each direction, with a very small height to the footings, as is the case in Chicago, steel beams are used to furnish the necessary transverse strength. For tall buildings, even when constructed on solid ground, it is sometimes found desirable to use steel-beam grillage footings to distribute the load. Such footings are usually cheaper than massive masonry footings, though they cannot, as a rule, compete in cost with footings of reinforced concrete.

The manner of using the beams is shown in Figure 35.

In preparing the footings, the ground is first carefully levelled and the bottom of the pier located. If the ground is not compact enough to permit of excavating for the concrete bed without the sides of the pit or trench falling in, heavy planks or timbers should be set up and fastened together at the corners and, if necessary, tied between with rods, to hold the concrete in place and to prevent its spreading before it has thoroughly set. A layer of Portland cement concrete, made in the proportion of 1, 2 and 4, and from 6 to 12 inches thick, according to the weight on the footings, should then be filled in between the timbers and well rammed and levelled off. If the concrete is to be 12 inches thick it should be deposited in two layers. Upon this concrete the beams should be carefully bedded in 1 to 2 Portland cement mortar, so as to bring them nearly level and in line with each other.

The distance apart of the beams, from center to center, may vary from 9 to 20 inches, according to the height of the beams, thickness of concrete and estimated pressure per square foot. They must not be so far apart that they will crush through the concrete (see Article 76.), and on the other hand there must be a space of at least 2 inches between edges of the flanges to permit the introduction of the concrete filling. As soon as the beams are in place the spaces between them should be filled with 1, 2 and 4 concrete, the stone being broken into pieces that will pass through a 1½-inch ring, and the concrete being well rammed into place, so that no cavities will be left in the center. The concrete must also be carried at least 3 inches beyond the beams on the sides and ends, and kept in place by planks or timbers.

73. CONCRETE BETWEEN LAYERS; BASE-PLATE, ETC.—If two or more layers of beams are used, the top of each layer

should be carefully levelled, after the concrete has been put in place, with 1 to 2 Portland cement mortar, not more than ½ an inch thick over the highest beams, and in this the next layer of beams should be bedded, and so on.

The stone or metal base-plate or footing should also be bedded in Portland cement mortar, not more than ¾ of an inch thick above the upper tier of beams.

After the base-plate or stone footing is in place, at least 3 inches of concrete should be laid above the beams and at the sides and ends; and when this is set the whole outside of the footings should be plastered with 1 to 2 Portland cement mortar.

74. QUESTION OF PAINTING STEEL BEAMS IN CONCRETE.—It was formerly the practice to thoroughly clean the beams with wire brushes before they were laid, and, while absolutely dry, to either paint them with iron paint or else to heat and coat them with two coats of asphalt.

The protection of steel when imbedded in concrete work seems to be so complete that many engineers are not insisting upon the painting of the grillage beams, as the cement in contact with the steel prevents any serious corrosion. In fact, probably greater strength and continuity of action is secured between the concrete and the steel of the footing when the latter is left unpainted, though such a combined action is not considered in calculating the strength of grillage construction.

75. NUMBER OF LAYERS OF BEAMS.—When iron and concrete foundations were first used in Chicago, railroad rails, on account of their lower cost, were employed to give the required transverse strength.

The footings were built up with five or six layers of rails, placed at right angles to each other, each layer diminishing in number until the upper surface was stepped off sufficiently, but not enough to exceed unduly the proper size of the column base As each layer of rails was laid, concrete was filled between and around them, and when completed the footing resembled a simple concrete pier.

The footings under the Rand and McNally building, Chicago, erected in 1891, were of this character, five layers of rails being used in most of the footings. In some of the footings the upper layer consisted of 12-inch beams.

Building up footings in successive tiers, however, is not as economical in the use of the steel as the method of building them up with two layers of deep beams.

It should also be borne in mind that the beams spread the load over the ground only by their transverse strength, and they should, therefore, be used in the same way that they would be were the foundation reversed, the wall or column becoming the support and the ground the load, as shown in Fig. 33.

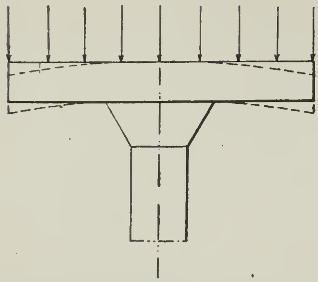

Fig. 33. Illustration of Flexure in Steel Beam Grillage.

76. NUMBER OF BEAMS IN THE UPPER COURSE.—When several beams are used in the upper course or layer, there is a tendency to concentrate the weight on the outer beams of the upper layer owing to the deflection of the beams below. The author therefore advocates the use of as few beams as practicable in the upper course and where the conditions will permit, either a single built-up girder or two heavy beams, and in the lower course the deepest beams consistent with economy. If the beams in the lower course permit of a spacing much greater than their height, a layer of rails should be imbedded in the top of the concrete to prevent the beams from breaking through. The rails, however, would in no way affect the stress or bending action in the beams.

For a further discussion of the use of steel beams in foundations, the reader is referred to an article by the author in *Architecture and Building* of August 24, 1895.

Examples of steel-beam and concrete footings are also given, with illustrations, in the *Engineering Record* of December 12, 1891, and June 1, 1895, and the later issues of the various journals on architecture and engineering contain numerous articles and illustrations of this method of construction.

77. EXAMPLE OF STEEL BEAM GRILLAGE ON SOLID ROCK.—The use of steel beam grillage foundations for tall buildings has become so universal that numerous accounts and illustrations of this type of construction may be found in the current numbers of the architectural and engineering publications.

While the use of grillage foundations is usually confined to compressible soils, it is sometimes employed to distribute the load of the columns over a solid rock foundation. A notable example of the use of grillages of steel beams being used for this purpose is found in the building for the Metropolitan Life Insurance Co., New York. In this structure the tower, which is the highest of all building

towers, is supported upon steel-beam grillage construction as illustrated in Fig. 34. From this figure it will be observed that the main columns are supported upon four tiers of steel beams while the secondary columns rest upon two tiers of beams. The grillage and column base is in each case entirely embedded in concrete.

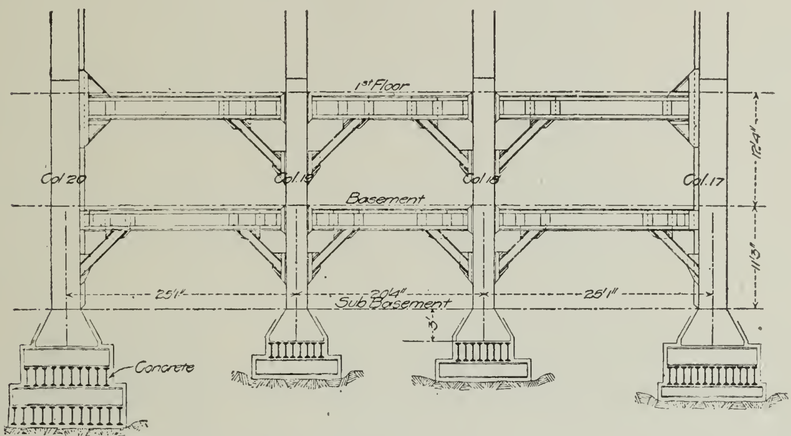

Fig. 34. Grillage Foundations on Rock. Metropolitan Life Insurance Company's Buildings, New York.

78. METHOD OF DETERMINING THE SIZE OF THE STEEL BEAMS.—As the purpose of the beams is to distribute the load coming from the foundation wall or base-plate evenly over the ground, so that the pressure on each square foot of the soil will be the same, it is obvious that the beams must have sufficient transverse strength to keep them from bending, so that they will settle as much at the outer ends as in the middle. The effect on the beams shown in Fig. 35, when resting on a compressible soil and heavily loaded from above, is to cause the ends of the beams to bend upward, thus stressing the beams the most in the middle; the stress in the beams being the same as if they were supported on a pier in the middle and loaded with a distributed load, as shown in Fig. 33.

79. DETAILS OF PROCEDURE AND EXAMPLE. GRILLAGE UNDER WALL.—The best method of determining the size of the beams is by computing the maximum bending moments for the steel beams and obtaining the required "section modulus" or "section factor," by dividing by the safe unit fiber stress of the steel. When the section modulus has been obtained, the corresponding

value may be found in the tables of the steel manufacturers' handbooks, from similar tables given herewith or in Kidder's "Architects' and Builders' Pocket-Book," and the beam of the required size and weight selected.

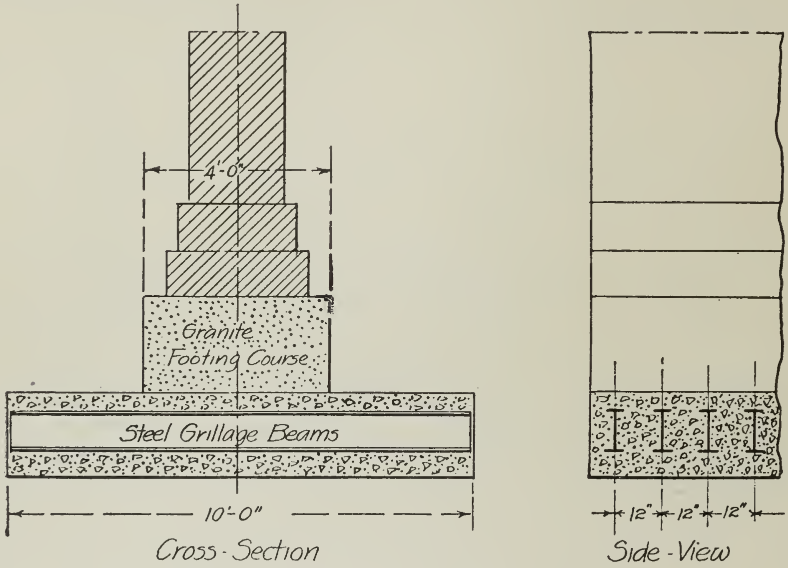

Fig. 35. Example of Steel Beam Grillage.

The maximum bending moment for a grillage beam may be obtained by the following formula:

$$M = \tfrac{1}{8} W (L-B) \qquad (4)$$

in which M is the maximum bending movement in inch-pounds; W the load in pounds on one beam of the grillage; L the length of the grillage beam in inches, and B the width of the upper tier or base in inches. See Fig. 35.

When the maximum bending moment M is divided by the safe unit fiber stress of the steel, usually taken at 16,000 pounds per square inch, the section modulus or Q is obtained. Or, this value may be found directly by the formula,

$$Q = \frac{W (L-B)}{128{,}000} \qquad (5)$$

The section modulus and several other properties of rolled steel I-beams of standard section are given in Table V.

TABLE V.

Section Modulus for Rolled Steel I-Beams of Different Sizes and Weights.

Depth of Beam	Weight Per Foot	Area	Thickness of Web	Width of Flange	Section Modulus Axis Square to Web
Ins.	Lbs.	Sq. In.	Ins.	Ins.	Q
20	90	26.4	.78	6.75	150.6
20	85	25.0	.76	6.45	139.4
20	80	23.5	.69	6.38	134.5
20	75	22.1	.66	6.16	124.7
20	70	20.6	.57	6.07	119.8
20	65	19.1	.50	6.00	114.9
18	80	23.5	.70	6.63	125.7
18	75	22.1	.62	6.55	121.3
18	70	20.6	.65	6.37	108.1
18	65	19.1	.64	6.17	98.5
18	60	17.6	.55	6.08	94.1
18	55	16.2	.47	6.00	89.6
15	80	23.5	.91	6.39	99.7
15	75	22.1	.81	6.29	96.0
15	70	20.6	.72	6.20	92.4
15	65	19.1	.62	6.10	88.7
15	60	17.6	.52	6.00	85.0
15	55	16.2	.55	5.85	74.3
15	50	14.7	.45	5.75	70.6
15	45	13.2	.46	5.56	59.5
15	42	12.4	.40	5.50	57.3
12	65	19.1	.88	6.25	65.6
12	60	17.6	.75	6.12	62.6
12	55	16.1	.63	6.00	59.7
12	50	14.7	.64	5.75	52.8
12	45	13.2	.51	5.62	49.8
12	40	11.8	.39	5.50	46.9
12	35	10.3	.44	5.22	38.8
12	31½	9.3	.35	5.13	36.7

Note—The above table is compiled from the Passaic Rolling Mill Co's. hand-book and agrees closely with the Standard Sections adopted by the American Steel Manufacturers Association.

Depth of Beam	Weight Per Foot	Area	Thickness of Web	Width of Flange	Section Modulus Axis Square to Web
Ins.	Lbs.	Sq. In.	Ins.	Ins.	Q
10	40	11.8	.58	5.21	35.7
10	35	10.3	.43	5.06	33.2
10	33	9.7	.37	5.00	32.3
10	30	8.8	.45	4.89	26.9
10	27	7.9	.37	4.81	25.5
10	25	7.3	.31	4.75	24.5
9	33	9.7	.51	4.95	27.2
9	30	8.8	.41	4.85	25.9
9	27	7.9	.31	4.75	24.6
9	25	7.3	.40	4.63	20.5
9	23⅓	6.9	.35	4.58	19.8
9	21	6.2	.27	4.50	18.7
8	27	7.9	.48	4.56	19.4
8	25	7.3	.40	4.49	18.6
8	22	6.4	.29	4.38	17.4
8	20	5.9	.32	4.20	15.0
8	18	5.2	.25	4.13	14.2
7	22	6.4	.36	4.17	14.3
7	20	5.7	.28	4.09	13.6
7	17½	5.1	.34	3.98	11.5
7	15	4.4	.23	3.88	10.6
6	20	5.7	.50	3.77	10.3
6	17½	5.0	.37	3.64	9.57
6	15	4.4	.25	3.52	8.81
6	12	3.6	.22	3.38	7.25
5	15	4.4	.38	3.25	6.77
5	13	3.8	.26	3.13	6.28
5	12	3.6	.34	3.13	5.39
5	9¾	2.9	.21	3.00	4.87
4	10	2.9	.39	2.69	3.42
4	7½	2.2	.20	2.50	2.93
4	6	1.8	.18	2.19	2.30

Owing to the tendency of the beams in bending, to concentrate the load on the outer edges of the masonry footing, and thus crush them, which action would have the same effect on the beam as lengthening the arm or projection (see article in *Architecture and Building* previously referred to), the author recommends that when the course

above the beams is of stone, brick or concrete, at least one-third the width of the masonry footing *be added to the actual projection.*

The application of the formulas (4) and (5) will be more clearly shown by the following example, the conditions of which are illustrated in Fig. 35. Owing to the size and to the nature of the material of the bottom course of the wall, the tendency to crush at the outer edge of this course is neglected:

Example I.—A building is to be erected on a soil of which the safe bearing power is but 2 tons per square foot, and the pressure on each lineal foot of wall is 20 tons. It is decided to build the footings as shown in Fig. 35. What should be the dimensions and weight of the beams?

Solution.—As the total pressure under each lineal foot of wall is 20 tons, and the safe bearing power of the soil 2 tons per square foot, the footings must be 20 ÷ 2, or 10 feet wide. As 4-feet granite blocks are used for the bottom course of the wall, the value of $L—B$ in formula (5) will be 72 inches; so that if the beams are spaced 12 inches on centers, the load W will be 20 tons, or 40,000 pounds, and

$$Q = \frac{40{,}000 \times 72}{128{,}000}, \text{ or } 22.5.$$

From Table (V), giving the Section Modulus for Rolled Steel I-Beams of Different Sizes and Weights, it is found that a 10-inch 25-pound beam is the most economical section to use for the grillage footing. The beam selected from the table has an excess of strength as its section modulus is 24.5. This, however, is as close a selection as can usually be made. When there are no values in the table corresponding closely with the section modulus required, a different spacing should be tried in order to obtain more economical results.

80. TABLE FOR FINDING SAFE LOAD ON GRILLAGE BEAMS.—The use of the above formulas and calculations may be avoided by referring to the following table giving the total *safe* load in tons of 2,000 pounds on a single beam, for the various sizes of steel I-beams, and for different values of $L—B$. The values in the table represent the safe load in tons which one beam of the grillage will support throughout its length.

By the use of this table, which is compiled from the Passaic Rolling Mill Co.'s hand-book, no calculations are necessary except

TABLE VI.

Safe Load in Tons of 2,000 Pounds on One Beam of Grillage Footings.

Beam		Projection both sides of Grillage Beam, or $L-B$, in feet										
Depth	Weight in Pounds Per Foot	5	6	7	8	9	10	11	12	13	14	15
20	80	......	119	102	89.6	79.8	71.7	65.2	59.8	55.2	51.2	47.8
20	75	......	111	95	83.2	73.8	66.5	60.5	55.4	51.2	47.5	44.3
20	70	......	......	91.2	79.8	71.0	63.9	58.1	53.2	49.1	45.6	42.6
20	65	......	......	87.5	76.6	68.2	61.3	55.7	51.0	47.1	43.8	40.9
18	75	......	108	92.4	80.8	71.8	64.7	58.8	53.9	49.8	46.2	43.1
18	65	......	87.5	75.0	65.6	58.4	52.5	47.7	43.8	40.4	37.5	35.0
18	60	......	83.6	71.6	62.8	55.8	50.2	45.6	41.8	38.6	35.8	33.4
18	55	......	......	68.4	59.8	53.2	47.8	43.5	39.8	36.8	34.2	31.9
15	65	94.6	78.8	67.6	59.2	52.6	47.3	43.0	39.4	36.4	33.8	31.5
15	60	......	75.6	64.8	56.6	50.4	45.4	41.2	37.8	34.9	32.4	30.2
15	55	......	66.0	56.6	49.6	44.0	39.6	36.0	33.0	30.5	28.3	26.4
15	45	......	52.8	45.4	39.6	35.2	31.7	28.8	26.4	24.4	22.7	21.1
15	42	......	50.8	43.6	38.4	34.0	30.6	27.8	25.4	23.5	21.8	20.4
12	60	66.8	55.6	47.8	41.8	37.1	33.4	30.4	27.8	25.7	23.9	22.3
12	55	63.6	53.0	45.6	39.8	35.4	31.8	28.8	26.5	24.5	22.8	21.2
12	45	53.2	44.2	38.0	33.2	29.5	26.6	24.2	22.1	20.4	19.0	17.7
12	40	50.0	41.6	35.8	31.3	27.8	25.0	22.7	20.8	19.2	17.9	16.7
12	35	41.4	34.6	29.6	25.9	23.0	20.7	18 8	17.3	15.9	14.8	13.8
12	31½	39.2	32.8	28.0	24.5	21.8	19.6	17.9	16.4	15.1	14.0	13.1
10	40	38.0	31.8	27.2	23.8	21.2	19.0	17.3	15.9	14.7	......	......
10	30	28.8	24.0	20.6	18.0	16.0	14.4	13.1	12.0	11.1	......	......
10	27	27.2	22.6	19.4	17.0	15.1	13.6	12.4	11.3	10.5	......	......
10	25	26.2	21.8	18.7	16.3	14.5	13.1	11.9	10.9	10.1	......	.....
9	30	27.6	23.0	19.7	17.3	15.4	13.8	12.6	11.5	10.2	......	......
9	27	26.2	21.8	18.7	16.4	14.6	13.1	11.9	10.9	10.1	......	......
9	25	21.8	18.2	15.6	13.7	12.2	10.9	9.9	9.1	8.4	......	......
9	21	20.0	16.7	14.3	12.5	11.1	10.0	9.1	8.3	7.7	......	......
8	25	19.8	16.5	14.2	12.4	11.0	9.9	9.0	8.3	7.6	......	......
8	20	16.0	13.3	11.4	10.0	8.9	8.0	7.3	6.7	6.1	......	......
8	18	15.1	12.6	10.8	9.5	8.4	7·6	6.9	6.3	5.8	......	......
7	20	14.5	12.1	10.4	9.1	8.1	7.3	6.6	6.1	......	......	......
7	15	11.3	9.4	8.1	7.1	6.3	5.7	5.1	4.7	......	......	......
6	17½	10.2	8.5	7.3	6 4	5.7	5.1	......	......	......	......	......
6	12	7.8	6.5	5.5	4.8	4.3	3.9	......	......	......	......	......

to determine the difference between the width of the superimposed footing or tier of beams, and the grillage beams. The results obtained by this table should agree with the results obtained from formulas (4) and (5).

Thus, in the above example, to use the table, it is simply necessary to look down the column headed 6 until the value nearest to 20 tons is found. This will indicate the lightest weight beam that can be used and this beam is found to be a 10-inch 25-pound beam having a strength value of 21.8 tons. A 9-inch 27-pound beam

would also do, but as it weighs more than the previously selected beam there would be no economy in using the shallower beam

When there is no value corresponding with the required one it is necessary to use formulas.

81. EXAMPLE. GRILLAGE UNDER PIER.—In the case illustrated in Fig. 36 the size of both the upper and lower beams are determined in the same way as in Example I., the value of *L—B* being taken for both tiers.

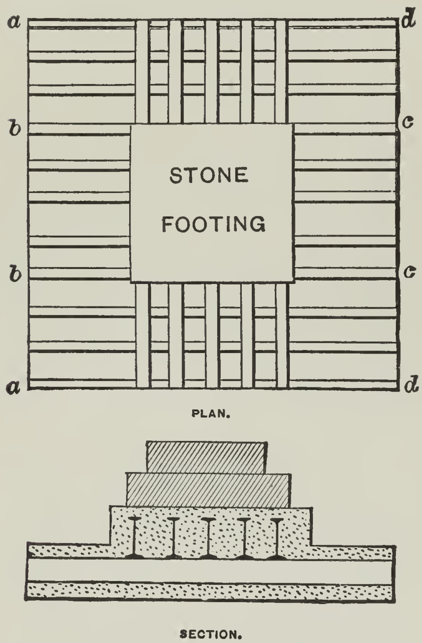

Fig. 36. Steel Beam Grillage Footing under Column.

Example II.—The basement columns of a ten-story building, resting on footings as shown in Fig. 36, are required to sustain a permanent load of 400,000 pounds. What should be the size of the beams in the footings, the supporting power of the soil being but 2 tons?

Solution.—By dividing the load by the bearing power of the soil the area of the footing is found to be equal to 100 square feet, so that the dimensions of the footing are 10 by 10 feet. The beams are arranged as shown in Fig. 36, and a cast-iron bearing plate 3 feet 6 inches square is used under the column. The distance between the centers of outer beams in upper tier is made 3 feet, thus making the value of *L—B* for both tiers equal to 7 feet.

Considering the upper tier of beams it is evident that, as there are five beams, each one must sustain a load of 400,000 pounds divided by 5 or 80,000 pounds, equal to 40 tons.

Looking down column headed 7 (Table VI.) the nearest value in the table to 40 tons is 43.6 which indicates a 15-inch 42-pound beam.

For the lower tier of beams the load on one beam will be found to equal 400,000 ÷ 11 (the number of beams in the tier) or 36,363

pounds. This amount reduced to tons equals 18.18 tons and from the table under column 7 it is found that a 10-inch 25-pound beam has a strength value of 18.7 tons, which though slightly excessive is the economical section.

82. COMBINED FOOTINGS. BASE-PLATES, ETC.—The deepest beam for the weight should always be used, and unless the beams in the upper tier have considerable excess of strength, the two outer beams should be heavy beams.

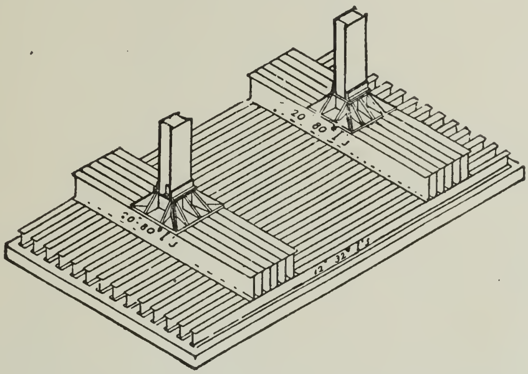

Fig. 37. Two Columns on One Grillage Footing.

When the footings carry iron or steel columns in the basement, as is generally the case, a cast-iron or steel base-plate should be used, as shown in Figs. 37 and 38. This plate should be bedded in Portland cement directly above the beams, as described in Article 75.

Two and even four columns are often supported on one footing, as shown in Figs. 37 and 38. In such cases the computation becomes more elaborate, and an engineer should be called in consultation, unless the architect is himself sufficiently familiar with such calculations.

Fig. 39 shows an arrangement in which a built-up base-plate or girder is used in place of the upper tier of beams. The author believes this arrangement much better than that shown in Figs. 36 and 37, though the cost of these heavy structural steel bases is very great and the details of their erection very exacting.

In placing the beams, it is essential that they be arranged symmetrically under the base-plate, as otherwise they will sink more at one side than at the other. When several unequally loaded col-

umns rest on the same footing, the equal distribution of the weight on the soil becomes a difficult problem.

C. TIMBER FOOTINGS

83. TIMBER FOOTINGS IN GENERAL.—For buildings of moderate height timber may be used to give the necessary spread to the footings, provided that water is always present. The footings should be built by covering the bottom of the trenches, which should be perfectly level, with 2-inch planks laid close together and longitudinally in the direction of the wall. Across these, heavy timbers should be laid, spaced about 12 inches on centers, the size

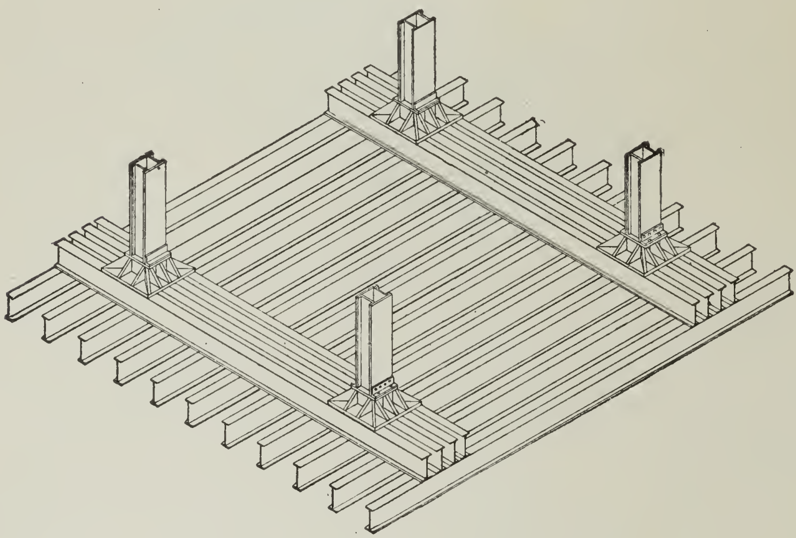

Fig. 38. Four Columns on One Grillage Footing.

of the timbers being proportioned to the transverse stress. On top of these timbers should be spiked a floor of 3-inch planks of the same width as the masonry footings which are laid upon them. A section of such a footing is shown in Fig. 40.

All of the timber work must be kept below low-water mark, and the space between the transverse timbers should be filled with sand, broken stone or concrete. The best woods for such foundations are oak, Georgia pine and Norway pine. Many of the old buildings in Chicago rest on timber footings.

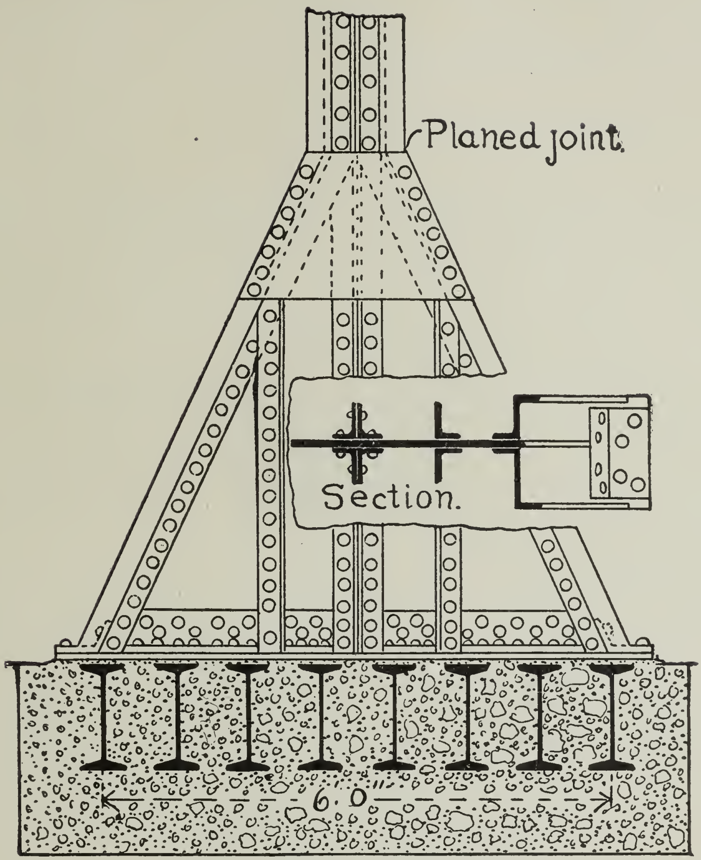

Fig. 39. Built-up Base for Column.

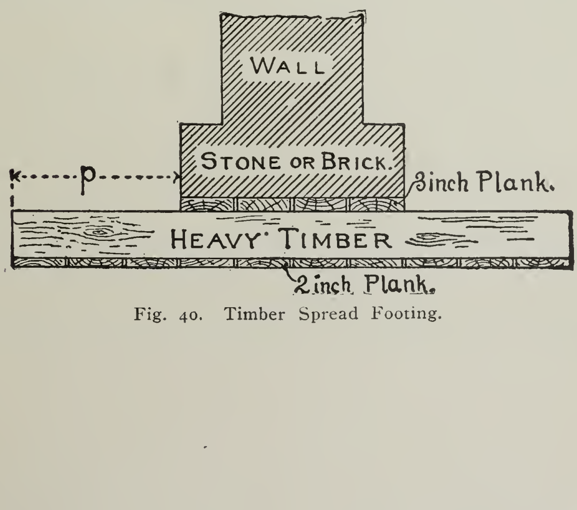

Fig. 40. Timber Spread Footing.

84. CALCULATION FOR THE SIZE OF THE CROSS TIMBERS.—The size of the transverse timbers should be computed by the following formula:

$$\text{Breadth in inches} = \frac{2 \times w \times p^2 \times s}{D^2 \times A} \ldots\ldots\ldots\ldots (6)$$

w representing the bearing power in pounds per square foot; p, the projection of the beams beyond the 3-inch planks in feet; s, the distance on centers of beams in feet, and D, the assumed depth of the beams in inches. A is the "constant for strength," and should be taken at 90 for Georgia pine, 65 for oak, 60 for Norway pine and 55 for common white pine or spruce.

Example I.—The side walls of a given building impose on the foundation a pressure of 20,000 pounds per lineal foot; the soil will support, without excessive settlement, only 2,000 pounds to the square foot. It is decided for economy to build the footings as shown in Fig. 40, using Georgia pine timber. What should be the size of the transverse timbers?

Solution.—Dividing the total pressure per lineal foot by 2,000 pounds, we have 10 feet for the width of the footings. The masonry footing we will make of granite or other hard stone, 4 feet wide, and solidly bedded on the planks in Portland cement mortar. The projection p of the transverse beams would then be 3 feet. We will space the beams 12 inches on centers, so that $s = 1$, and we will assume 10 inches for the depth of the beams. Then by formula (6),

$$\text{the breadth in inches} = \frac{2 \times 2000 \times 9 \times 1}{100 \times 90} = 4,$$

or we should use 4 by 10-inch timbers, 12 inches on centers. If common pine timber were used we should substitute 55 for 90, and the result would be 6½ inches.

85. BUILDINGS ON QUICKSAND.—When building on quicksand it is often advantageous to lay a floor of 1-inch boards in two or more layers at right angles to each other on which to start the concrete footings.

86. FOUNDATIONS FOR TEMPORARY BUILDINGS.—When temporary buildings are to be built over a compressible soil, the foundations may, as a rule, be constructed more cheaply of wood than of any other material, and in such cases the durability of the timber need not be considered, as good sound timber will

last two or three years in almost any place if thorough ventilation is provided.

The World's Fair buildings at Chicago (1893) were, as a rule, supported on timber platforms, proportioned so that the maximum load on the soil would not exceed 1¼ tons per square foot. Only in a few places over "mud holes" were pile foundations used.

The platform foundations consisted of "3-inch pine or hemlock planks, with blocking or transverse beams on top, to distribute uniformly over all the planks, the pressure from the loads, and to furnish support for the posts which carried the caps supporting the floor joists and posts of the building. The blocking was well spiked to the platform planks and posts, and the caps and the sills were drift-bolted."

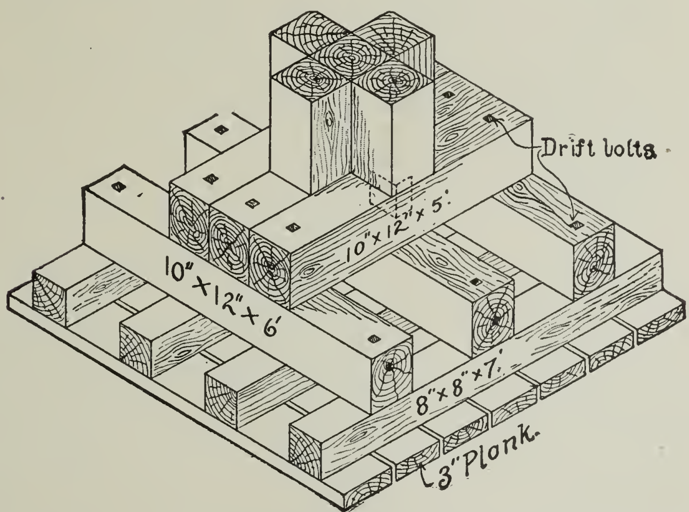

Fig. 41. Temporary Timber Column Foundation. World's Fair Buildings, Chicago, 1893.

Fig. 41 shows the general arrangement of the blocking under the posts.

3. MASONRY WELLS

87. MASONRY WELLS UNDER CITY HALL, KANSAS CITY, MO.—When it is necessary to support very heavy buildings on compressible or filled-in soil, where piles or spread footings cannot be used, or are not considered desirable, wells of masonry, sunk to bed-rock or hard-pan, will generally prove the method of securing an efficient foundation which comes next in point of economy.

The wells are arranged as isolated piers, and the walls of the superstructure are carried on steel girders resting on these piers.

The manner in which such wells or piers should be used can probably be best explained by describing those under the City Hall of Kansas City, Mo., which was one of the first instances in which such wells were used in this country.*

"The site of the City Hall was formerly a ravine between abrupt bluffs. These had been so cut away and levelled as to leave a 50-foot filling of rubbish under two-thirds of the building and a solid clay bank under the other third. The fill was made by a public dump. Pile foundations were objectionable on account of the dryness of the fill and the anticipated tendency of the piles to rot therein. Ordinary trenching was considered too expensive and dangerous, therefore a system of piers was chosen, and a cylindrical form was adopted, so that the excavation could be done by a large steam-power auger, followed by a 3/16-inch caisson filled with vitrified brick. The caissons were made in 5-foot lengths of the same thickness throughout, the joints being made with 3"x½" splice plates, riveted to the inside of the shell.

"The piers were of vitrified brick, 4 feet 6 inches in diameter, laid in hydraulic cement mortar, grouted solid in each course, and well bonded in all directions. The piers were sunk to bed rock of oolitic limestone, 8 feet thick, and capped with cast-iron plates (Fig. 42) and steel I-beams, which supported the walls. To the top of the beams was riveted a ¼-inch plate of boiler iron, on which the brickwork of the walls was built, as shown in Fig. 43.

"Between the beams, and 1 foot on each side and underneath them, is a concrete filling, so that the beams are entirely encased in masonry.

"Piers having excessive loads are reinforced by 12-inch Z-bar columns resting on rock bottom (Fig. 44). These columns pass through the cast-iron caps, so that the loads resting on the columns are separate from those on the brick piers (an essential provision). Essentially the whole system is intended to secure the direct transmission of the entire weight to the solid rock by so arranging the interior construction that each subdivision is carried by an adequate isolated pier. The piers are of uniform size, and their loads are equalized by spacing them at proportionate distances apart."

88. MASONRY WELLS UNDER STOCK EXCHANGE BUILDING, CHICAGO.—Another instance of the use of masonry wells or deep piers is in the foundation of the Stock Exchange building in Chicago.

"The foundation is generally upon piles about 50 feet long, driven into the hard clay which overlies the rock. Next to the *Herald* Building, however, which adjoins it, wells were substituted, lest the shock of the pile driver close to its walls should cause settlements and cracks. A short cylinder,

* The following description is an abstract of a short paper presented by the architect of the building, Mr. S. E. Chamberlain, of Kansas City, to the twenty-fourth annual convention of the American Institute of Architects. The illustrations were prepared in the office of the *Engineering Record* from the architect's drawings. Several more illustrations are given in the *Engineering Record* of April 2 and 16, 1892.

Fig. 43.

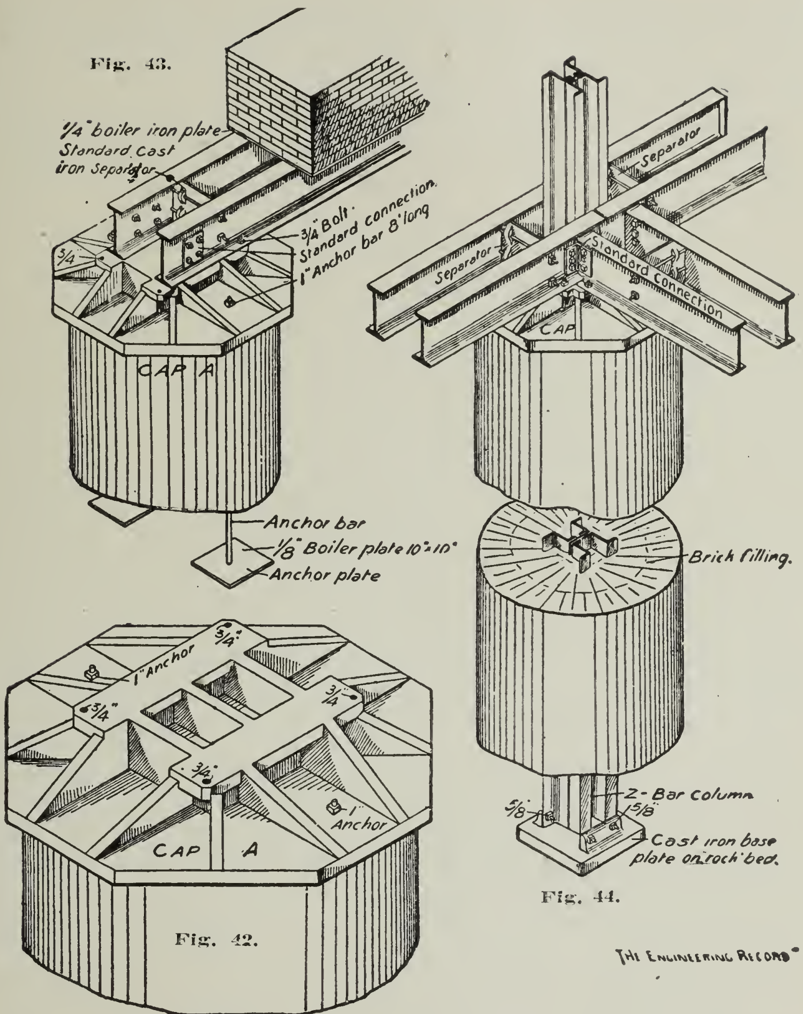

Fig. 44.

Fig. 42.

Figs. 42, 43, 44. Masonry Wells Under City Hall, Kansas City, Mo.

5 feet in diameter, made of steel plate, was first sunk by hand, reaching below the footings of the *Herald* Building. Then around and inside the base of the cylinder sheet piles, about 3½ feet long, were driven, and held in place by a ring of steel inside their upper ends. The material inside the sheeting was excavated and a similar steel ring was placed inside their lower ends. By means of wedges the lower ends of the sheeting were forced back into the soft clay until another course could be driven outside the lower ring. This operation was repeated until the excavation had reached the hard clay about 40 feet below the cellar. In this material the excavation was continued with-

out sheeting in the form of a hollow truncated cone to a diameter of 7½ feet, and the entire excavation was filled with concrete. The wells are spaced about 12 feet. The loads upon them vary; some of them will carry about 200 tons.

"The material excavated was a soft, putty-like clay to a depth of 40 feet, where a firm clay was reached deemed capable of carrying the weight proposed."*

4. CAISSON FOUNDATION CONSTRUCTION

89. GENERAL DESCRIPTION.—Caissons are constructed of timber or metal and are made cylindrical, square, or rectangular in section, open at both ends, or closed at the top or bottom. This construction is employed where it is necessary to penetrate a considerable depth of soft soil, permeated with water, to the solid rock or hard-pan beneath. Caissons are named after the manner of their use, as "open," "erect," and "inverted." The "open" caisson is simply a cylinder or open box made of planks, timbers, or sheet-steel, without top and bottom. It is sunk by excavating inside, and allowing it to settle by its own weight, or by a load on a platform constructed upon the top. The sides are made water-tight, and any water coming in around the bottom edge or through the soil at the bottom is pumped out by hand, steam pump, or pulsometer.

Caissons constructed with water-tight bottoms are seldom used in building construction, but are frequently employed in building the foundations of bridges or other foundations in water. When so used, they are towed to the desired position, and when properly located, and guided, are sunk by being filled with masonry or concrete. Such caissons are usually called "erect" caissons.

90. INVERTED CAISSONS.—The "inverted" caissons are the ones most frequently and successfully used in the construction of important foundations carried to hard-pan or solid rock through strata of soft soil. They take the form of water-tight boxes or cylinders. Closed at the top and open at the bottom, they are strongly braced, and are usually made of steel plates, though sometimes constructed of heavy timbers. The operation of sinking them consists in building masonry upon the top, and in carrying on the excavation inside and around their cutting-edge.

91. THE VACUUM SYSTEM.—Two systems are successfully

* "Foundations of High Buildings." W. R. Hutton. Read before the Congress of Architects at Chicago, 1893.

used in sinking "inverted" caissons, namely, the "vacuum" system, and the "plenum" system.

In the former the air is exhausted from the interior of the caisson and the excess of atmospheric pressure upon its top assists in forcing it downward; while on account of the partial vacuum inside, the water around the excavation flows rapidly under the edge and into the caisson, thus loosening the soil and allowing it to be drawn out with the water.

92. THE PLENUM SYSTEM.—The "plenum" system is the one generally used, however. In this system water is prevented from flowing into the caisson by creating inside of it an air pressure, the excess of which over that of the atmosphere is sufficient to equalize the pressure of the water outside. This air pressure is provided by powerful air-pumps. The workmen enter the caisson through an air-lock, placed in a tube, or cylinder, leading from the caisson, and consisting of an air-tight compartment with two doors. (See Fig. 49.) In operating the air-lock, the workman enters through the first door, or trap, and closes it, allowing the air under pressure in the caisson to flow in slowly until the pressure in the air-lock is equal to that in the caisson, when the door to the caisson is opened and the workman allowed to enter. If the air were suddenly let into the air-lock, the physical strain upon the men would be severe and dangerous.

The material from the excavation is usually hoisted in buckets, operated through air-locks, and the work is carried on in this way until the caisson has reached the required depth, when it is filled with concrete or masonry, and the piers constructed upon the top.

93. CAISSONS IN THE MANHATTAN LIFE INSURANCE CO.'S BUILDING, NEW YORK.—Although caissons have been for some time extensively used in constructing the foundations of bridge piers, they were not, until a relatively recent date, used for the foundations of buildings in this country. The first instance was that of the building for the Manhattan Life Insurance Company, near the foot of Broadway, New York City; Messrs. Kimball & Thompson, Architects; Charles O. Brown, Consulting Engineer.

The method there employed proved perfectly satisfactory, and cost only about 8 or 9 per cent of the estimated cost of the building. The following is a short description of the manner in which the founda-

tions were constructed and the superstructure supported thereon, in this early example:*

"The building occupies an area of about 8,200 square feet, and is seventeen stories high on Broadway and eighteen on New Street. The height from the Broadway curb to the parapet of the main room is 242 feet, and the dome and tower rises 108 feet above the parapet. All the walls, together with the iron floors and roof (which are very heavy), are directly supported by thirty-four cast-iron columns, which sustain an estimated weight of about 30,000 tons.

"The great height and massive metal and masonry construction impose enormous loads on the foundations, amounting to as much as 200 tons for some single columns, and giving about 7,300 pounds per square foot over the whole area of the lot. This enormous weight could not be safely carried on the natural soil, which is essentially of mud and quicksand to the bed rock, which has a fairly level surface about 54 feet below the Broadway street level. Above this rock the water percolates very freely, standing at a level of about 22 feet below the Broadway street line, and therefore making excavations below this plane difficult and costly. If piles had been driven as close together as the city regulations permit—*i. e.*, 30 inches center to center over the whole area, about 1,323 might have been placed, and would have carried an average load of 45,300 pounds each, which was inadmissible, the statute laws of New York allowing only 40,000 pounds each on piles 2 feet 6 inches apart and with a smallest diameter of 5 inches.

"Special foundations were therefore necessary, and it was imperative that their construction and duty should not jeopardize nor disturb the existing adjacent heavy buildings which stand close to the lot lines. On the south side the six-story Consolidated Exchange building is founded on piles which are supposed to extend to the rock. On the north the foundations of a four-story brick building rest on the earth about 28 feet above the rock, and were especially liable to injury from disturbances of the adjoining soil, which was so wet and soft as to be likely to flow if the pressure was much increased by heavy loading or diminished by the excavation of pits or trenches.

"In view of these conditions it was determined to carry the foundations on solid masonry piers down to bed rock. The construction of the piers by the pneumatic caisson process was, after careful consideration by the architects, backed by opinions from prominent bridge engineers as to its feasibility, adopted.

"The smaller caissons were received complete and the larger ones in convenient sections, bolted together when necessary, and located in their exact horizontal positions, calked and roofed with heavy beams to form a platform, on which the brick masonry was started and built up for a few feet before the workmen entered the excavating chamber and began digging out the soil. The removal of the soil allowed the caissons to gradually sink to the rock below without disturbing the adjacent earth, which was kept from flowing in by maintaining an interior pneumatic pressure slightly in excess of the

* Abstract from a very full description, with ten illustrations, published in the *Engineering Record* of January 20, 1894.

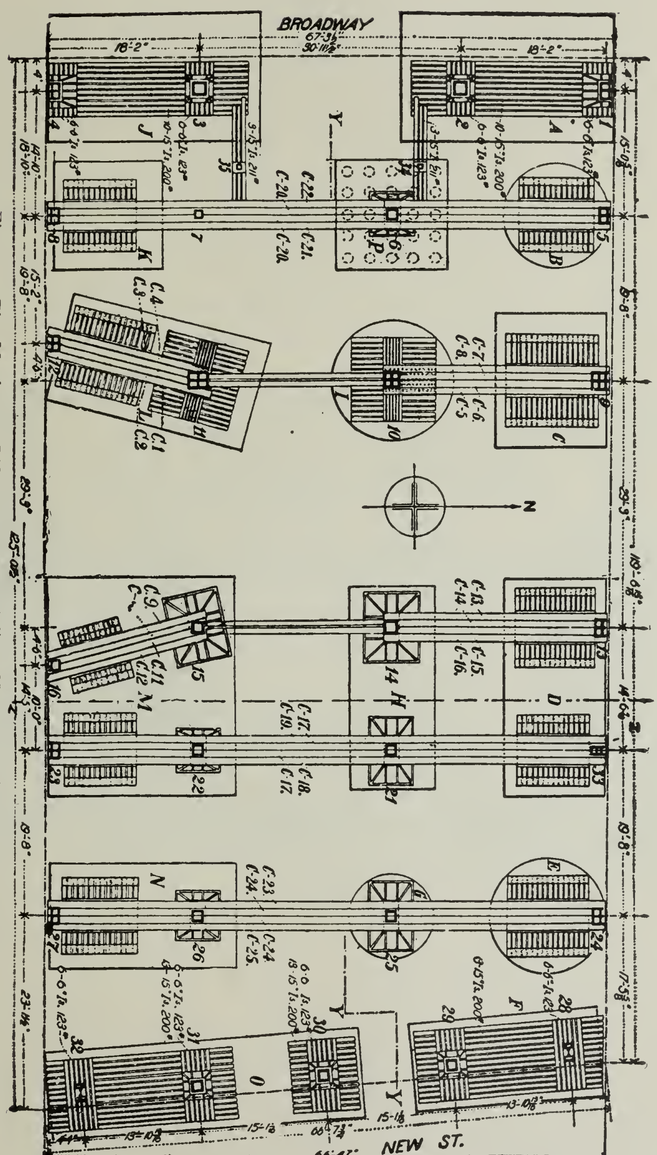

Fig. 45. The Manhattan Life Insurance Building, New York City. Plan of Piers.

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outside hydrostatic pressure due to the distance of the bottom of the caisson below the water line.

"The adjacent buildings were shored up at the outset and scrupulously watched, observations being made to determine any possible displacement or injury of their walls, which were not seriously damaged, though the pressure they exerted on the yielding soil tended to deflect the caissons which were sunk within a foot of them. They were kept in position by excess of loading and excavating on the edges that tended to be highest. The caissons encountered boulders and other obstructions, and were sunk through the fine soil and mud at an average rate of 4 feet per day. No blasting was required until the bed rock was reached and levelled off under the edges and stepped into horizontal surfaces throughout the extent of the excavating chamber. Usually one caisson was being sunk while another was being prepared, there being only one time when air pressure was simultaneously maintained in two caissons. Generally about eight days were required to sink each caisson."

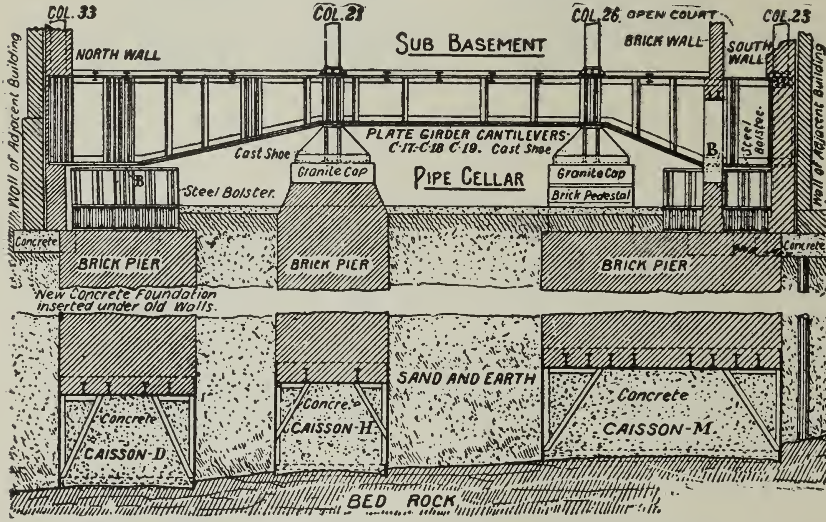

Fig. 46. The Manhattan Life Insurance Building, New York City. Transverse Section.
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The first caisson was delivered at the site April 13, 1893, and the last pier was completed August 13, 1893.

"After the caissons were sunk to bed rock, and the surface cleared and dressed, the excavating chambers and shafts were rammed full of concrete, made of 1 part Alsen Portland cement, 2 parts sand and 4 parts of stone, broken to pass through a 2½-inch ring. The superimposed piers were built of hard-burned Hudson River brick, laid in mortar composed of 1 part Little Giant cement to 2 parts sand."

Fig. 45 is a plan showing the piers, all of which, except *P*, which is built on twenty-five piles, are founded on caissons of the same size, and the bolsters on top of them, together with the girders and the columns, which are indicated by solid block cross sections.

"Cylindrical caissons are the most convenient and economical, and would have been used throughout if the conditions had permitted, but the positions of the columns and the necessity of distributing the load along the building lines and other considerations determined the use of rectangular ones, except in four cases." All the caissons were 11 feet high, made of ½-inch and ⅜-inch plates and 6 by 6-inch angle framework, stiffened with 7-inch bulb-angles, vertical brackets and reinforced cutting edges.

The columns supporting the outer side walls of the buildings were located so near the building line that they were near or beyond the outer edge of the foundation piers, as shown in Fig. 45, so that if they had been directly supported thereon they would have loaded them eccentrically and produced undesirable irregularities of pressure. This condition was avoided and the weights transmitted to the centers of the piers by the intervention of heavy plate-girders, which supported the columns in the required positions and transferred their weights to the proper bearings above the piers. From these bearings the load was distributed over the whole area of the masonry by special steel bolsters.

Fig. 46 is a transverse section at *D-H-M,* Fig. 45, showing the quadruple girder *C,* 17-18-19, and the manner in which it supports columns 23 and 33. The cantilever is made continuous across the building, with intermediate supports under columns 21 and 22.

Soon after this pneumatic caisson foundations were used in the construction of the American Surety building, New York, a full description of which is given in the *Engineering Record of* July 14, 1894. Caisson foundations, whether in the shape of wells or in the pneumatic form, should be used only under the advice or direction of a competent engineer.

94. CAISSONS IN THE SINGER BUILDING AND THE UNITED STATES EXPRESS COMPANY'S BUILDING, NEW YORK.—Several interesting examples of recent foundation construction, in which the pneumatic caisson has been successfully employed, are to be found in the Singer building and in the United States Express Company's building, both located in New York City.

Beneath the Singer building it was necessary to excavate to bed-rock, found at a depth of 90 feet below the curb. This bed-rock was overlaid with a stratum of hard-pan about 15 feet deep. The foundation plan of the building consists of rectangular and cylindrical piers of concrete, arranged as shown in Fig. 47, all of these piers being constructed by means of pneumatic caissons. As the Singer building is 41 stories in height, with a tower 612 feet above the street level, the load upon the foundations is very great, amounting to, approximately, 27 tons per square foot, and including the

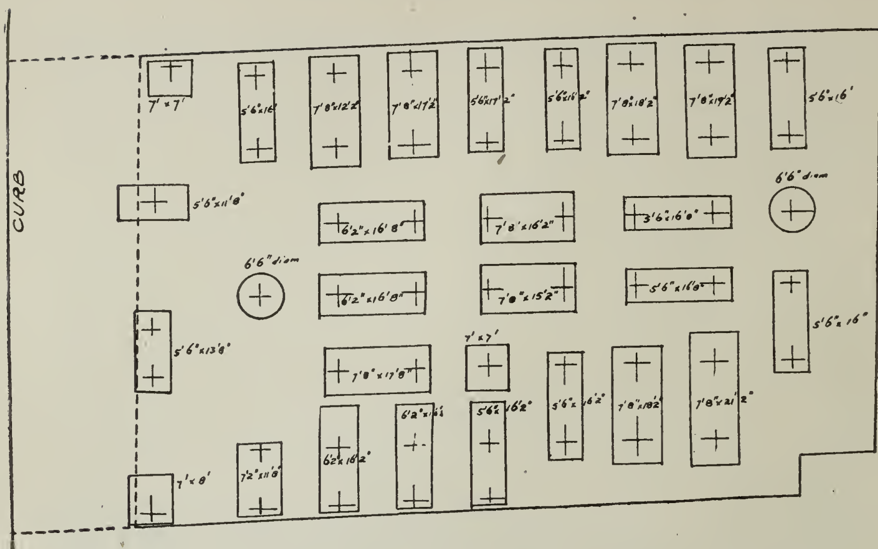

Fig. 47* Plan of Caisson and Pier Foundation, Singer Building, New York.

load due to wind pressure, the full dead load and about 60 per cent of the maximum live load.

Fig. 48 shows the finished concrete piers constructed by means of the caissons, and supporting the steel frame and curtain-walls of the building along the party-line, with the interior column support carried some distance below the basement floor level.

In the construction of the United States Express Company's building, which is a 23-story structure, it was necessary to use pneumatic caissons on account of the fluid character of the soil, made treacherous by the tidal waters of the Hudson River. The material found on the site of this building consisted of 9 feet of earth, loam and fill, and an average of 18 feet of quicksand overlying a stratum of hard-pan 14 feet thick; bedrock was found at a depth of 41 feet below the curb, and to this it was necessary to extend the foundations.

For the construction of this building, caissons or working chambers were provided, consisting of bottomless boxes, rectangular in cross-section and about 6 feet wide, with a minimum length of 35 feet 4 inches, and a width of 6 feet. The walls of these caissons were built up of six courses of timber, which were secured by ¾-inch drift-bolts 2 feet long, and tied together vertically by 1-inch

* From *Architects' and Builders' Magazine*, January, 1907.

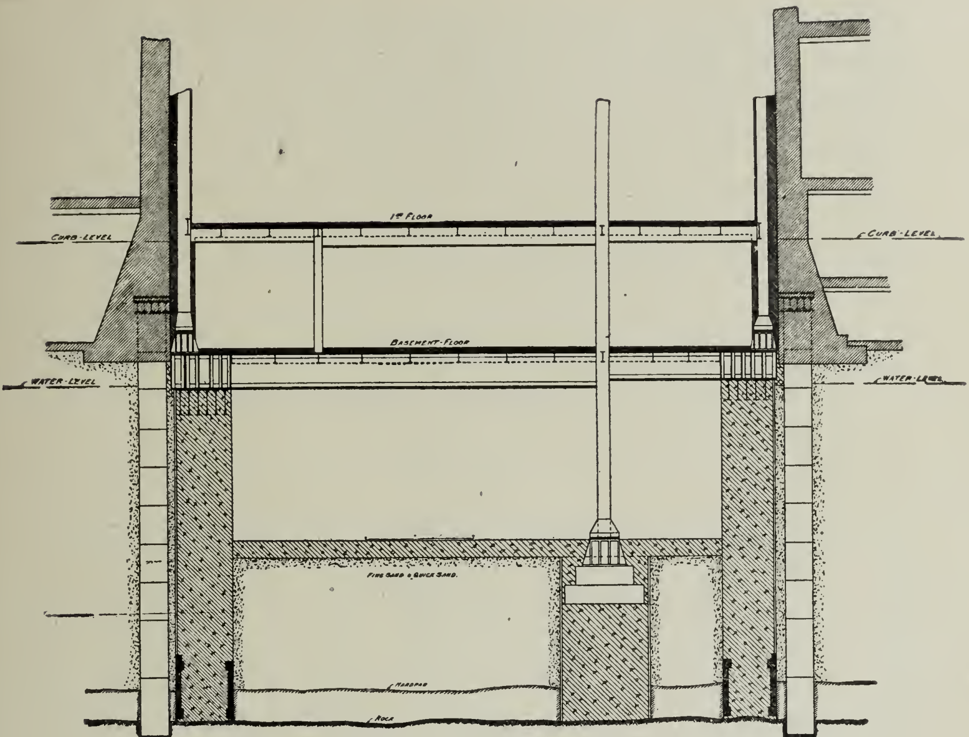

Fig. 48* Section of Caisson and Pier Foundation, Singer Building, New York.

screw-rods, placed 3 feet apart; and the cutting edge was provided with a 6 by 4-inch steel angle. The heaviest caisson weighed in the neighborhood of 10 tons, and was large enough for six men to work inside of it; a roof was formed over it with 1⅞-inch tongued-and-grooved boards, and connected with this was a steel tube or shaft. The shaft was surmounted by what is known as the "Moran" air-lock. When the shaft or working tube was in place, two 10-feet sections of temporary wooden forms were built upon the top of the caisson, a layer of cement mortar 6 inches thick was spread over the temporary roof, and upon this 24 inches of 1, 2 and 4 concrete was placed and allowed to set for 24 hours. This construction formed a concrete slab strong enough to carry the concrete forming the pier. The 10-feet sections were then filled with concrete, and when this had set, additional forms were raised and more concrete put in place. As the caisson was brought

*From *Architects' and Builders' Magazine*, January, 1907.

to the water level, compressed air was pumped into it, or into the bottom working chambers, to expel the water from the lower or cutting edge, and to allow the work of excavation to proceed inside. Thus undermined, the caisson sank by the great weight of the concrete above, and where necessary the weight was augmented by piling pig-iron on top. When the caisson reached bed-rock and a pier of concrete extended from its roof to the top of the pier, the interior of the working chamber and the shaft connecting the latter with the outer air were filled with rich concrete.

In operating the caisson construction in both this building and the Singer building, the above mentioned Moran air-lock was employed. This air-lock is illustrated in Fig. 49, and is the inven-

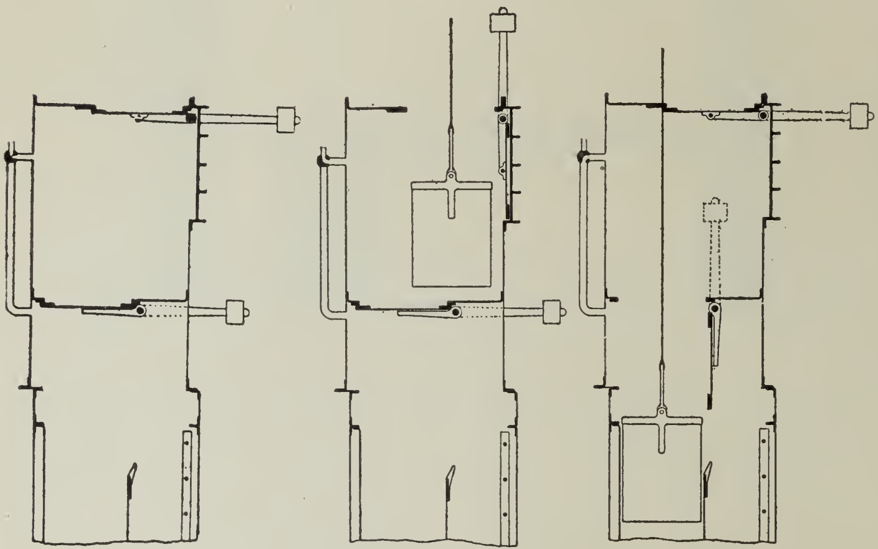

Fig. 49.* Section of Moran Air-Lock.

tion of Mr. Daniel C. Moran. In operation it is similar in principle to the ordinary river-lock, in that one door is always closed, thus maintaining the pressure in the working chamber with a minimum of leakage. From the figure it will be observed that the two doors of the air-lock are hinged and counter-weighed, allowing them to be operated readily when the pressure is relieved or equalized; and they are made air-tight by means of heavy rubber gaskets around the edge. In order to enter the caisson the workman descends the

* From *Architects' and Builders' Magazine*, January, 1907.

shaft and passes through the upper opening into the chamber or air-lock, when the door is closed and a valve opened, allowing the air to flow from the caisson or lower part of the shaft into the chamber or air-lock, and to thus equalize the air pressure so that the lower door may be opened and access had to the lower part of the tube and thence to the caisson. In hoisting the dirt or silt the process is reversed by hauling the bucket up into the air-lock, the hoisting rope passing through a stuffing-box in the upper door. By closing the lower door the upper one may be opened and the bucket hoisted from the lock and up the shaft. The loss of air in each operation is the volume contained in the air-lock or chamber in the shaft between the two doors.

95. FOUNDATIONS OF HIGH BUILDINGS.—In preparing the foundations for high buildings the same principles apply as for other buildings, except that as the loads on the foundations are so much greater, the footings must be proportioned with the utmost care.

When building on firm soils it is only necessary to observe carefully all the precautions given in Chapter I.; and when building on compressible soils one of the methods described in this chapter should be employed, always, however, under the advice of an experienced engineer.

5. CANTILEVER FOUNDATION CONSTRUCTION

96. GENERAL DESCRIPTION.—In thickly built-up districts of cities, where the ground is of great value and where every available square foot of space must be utilized, it is necessary to build close to the party-lines. Frequently the party-walls of the adjoining buildings are entirely inadequate for the support of the floor systems of the newer heavy structure, so that new foundations must be provided. If the building to be erected is many stories high, foundations of considerable area are required. Such foundations, under the City Laws and Ordinances, must be entirely within the party-line of the owner's property, unless it is proposed to underpin and shore the old building, and erect a party-wall for both the new and old structure. This is not always desirable, on account of the expense and the likelihood of difficulties with the adjoining owners and tenants.

By building the footing entirely inside of the party-line, as shown in Fig. 50, the line of action of the weight W does not coin-

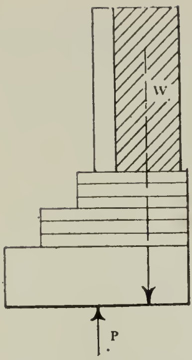

Fig. 50. Footing Inside of Party Line. Center of Pressure Outside of Center of Base.

cide with the line of action of the resultant of the pressure P from the foundation soil, so that there is a tendency to throw outward the walls of the building and to cause unequal pressures upon the soil. In order to provide a foundation which will give an equal pressure upon each square foot of soil, the cantilever system of foundation construction shown in Fig. 51 is used. In this figure the existing wall against which it is desired to build is shown at *a*, and the wall column and the curtain-wall of the new structure supported by the cantilever beam is indicated at *b*. By arranging the footing *c* under the cantilever beam as shown, the undermining of the old wall of the adjoining building is avoided and a uniform pressure is brought to bear on the soil beneath the footing *c*. As the weight of the curtain-wall, and of one-half of the floor loads of all the stories between columns *b* and *d*, is concentrated on the overhanging end of the cantilever, there is a lifting tendency on the column *d*; so that, for stability of construction, the product of the force represented by the weight W by its lever arm x must equal the product of the force represented by the weight W_1 by its lever arm x_1.

From Fig. 51 it will be observed that the footings are of concrete

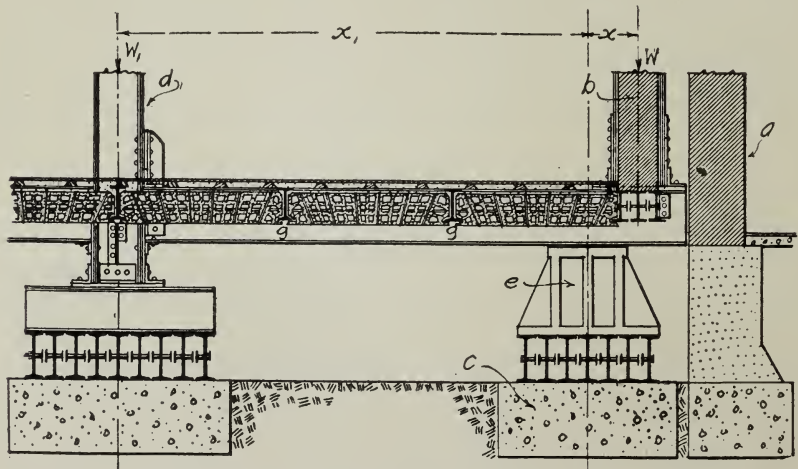

Fig. 51. Examples of Cantilever Foundation Construction. Loss of Head-room.

and that the weight is distributed over them by means of the grillage beams. Usually a heavy cast-iron or structural steel bed-plate or bearing-plate transmits the load at the overhanging end of the cantilever to the grillage, as at *c*. The beams marked *g* are framed in between the several cantilever beams or girders, and support what would in this instance be the basement floor, as there is, with this construction, insufficient head-room below the bottom of the cantilever beams to form a basement.

97. CANTILEVER CONSTRUCTION WITH EXTENDED HEAD-ROOM.—The type of cantilever foundation just described provides the cantilever beams or girders directly over and not far removed from the foundation footing and immediately under the basement floor. Such construction results in a considerable waste of head-room or vertical distance, which is not always advisable, so that the cantilever construction shown in Fig. 52 is frequently employed. In this illustration the cantilever forms the main supporting member of the first floor construction, and consists of a built-up plate-girder of box section, as at *a*. Upon the overhang end, where

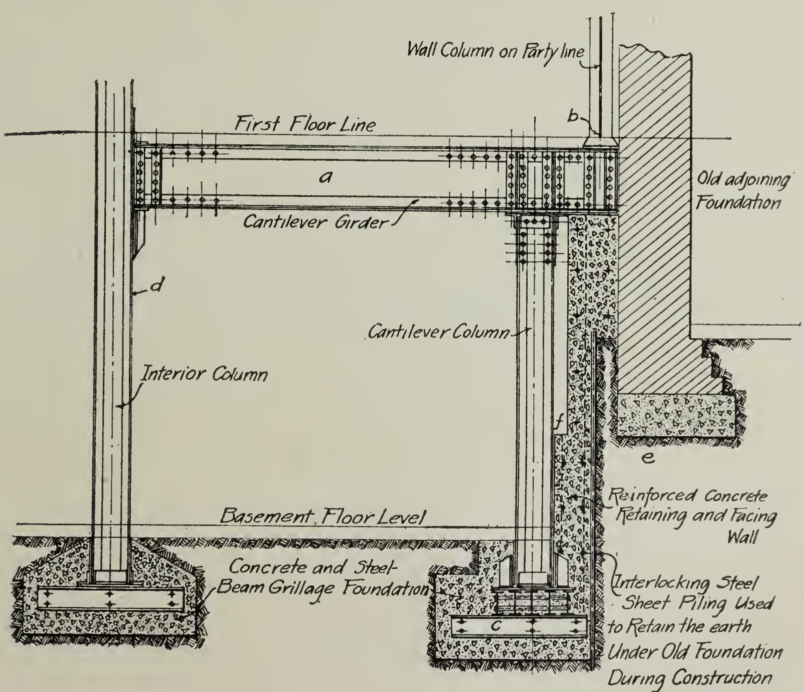

Fig. 52. Example of Cantilever Foundation Construction. Bacement Head-room Retained.

it is strongly braced against buckling by means of stiffeners or angles, the wall columns and curtain-walls are supported as at *b*. The cantilever, instead of being supported almost directly upon the foundation, is carried by a structural steel column, some distance inside of the party-line, and this column in turn is supported by the grillage foundation, as at *c*. The other end of the cantilever girder is secured to the interior structural steel column *d*. Where the load upon the overhanging end of the cantilever is excessive and the leverage is sufficient to cause too great a lifting tendency upon the interior column *d*, the latter must be designed with a heavy foundation and anchor-bolts, so that there will be sufficient resistance to this upward action.

In the illustration, Fig. 52, the bottom of the foundation footing under the wall of the adjoining building does not extend down to the depth of the new basement floor level; so that, in order to carry on the excavation, steel sheet-piling is driven along the wall line to prevent the earth from sliding from under the old footings, as at *e*. This sheet-piling is afterwards backed up with concrete, which is incorporated with the concrete of the grillage footing, and forms an adequate retaining-wall to prevent the earth under the old wall from being disturbed. While the ledge of concrete, as at *f* in the figure, along the basement wall can hardly be considered as objectionable, this construction may be done away with by underpinning the old wall.

Cantilever foundation construction involving the use of structural steel is always expensive but sometimes unavoidable. In many instances when it must be used, the cost may be materially reduced by using footings and foundation constructions of reinforced concrete.

Chapter III.

Masonry Footings and Foundation Walls, Shoring and Underpinning

I. MASONRY FOOTINGS

98. PURPOSE OF FOOTINGS.—Footings under walls are used for two purposes: 1. To spread the weight over a greater area. 2. To add to the stability of the wall. Under buildings of only two or three stories, the latter function is generally the more important.

All walls should therefore have a footing or projecting course at the bottom of brick, stone or concrete.

The width of the footings should be at least 12 inches wider than the thickness of the wall above, and should also be such that the pressure per square foot under the footings will not exceed the safe bearing power of the soil nor of the material on which it rests. (See Article 17.)

99. CONCRETE FOOTINGS.—For nearly all classes of buildings built on solid ground, cement concrete makes probably the best material for the bottom footing course, especially for the money expended. Concrete possesses the advantage over large blocks of stone of having considerable transverse strength, so that when fully hardened it is much like a wide beam laid on top of the ground under the walls; and should a weak spot occur in the ground under the footing, the latter would probably have sufficient transverse strength to span it if it were not very large. Concrete must also necessarily bear evenly over the bottom of the trenches, so that there can be no cavities, as is sometimes the case with stone footings. In localities where large blocks of granite or flagging cannot be cheaply procured, concrete makes much the cheapest footing.

As concrete is now available in all localities, many architects and engineers believe it advisable to use it in place of bricks for foot-

ings. While good hard-burned bricks are very durable when used above ground, they are not so durable when used under ground; and in the latter case there is a tendency to deteriorate, due probably to the continuous saturation and to the action of frost.

In stiff soil, trenches for the concrete footings should be dug below the general level of the excavation and of the exact width of the footings, so that when the concrete is put in and tamped it will bear against the sides as well as on the bottom of the trenches. In sandy soils this of course cannot be done, and planks must be set up and held in place by stakes to form the sides of the trenches. After the cement has set, but not before, the planks may be removed.

Concrete for footings should be mixed in the proportion of 1 part of cement to 2 parts of sand and 4 parts of stone for natural cements, and 1 to 2½ and 5 for Portland cements. The thickness of the concrete should be one-fourth of its width, and never less than 12 inches, except under very light buildings. The concrete should be put in in layers about 6 inches thick. If the footing is considerably wider than the wall it may be stepped in by setting up planks to hold the upper layers of concrete, or a stone footing of proper width may be placed on top of the concrete, as in Fig. 53. The latter is apt to give the best results.

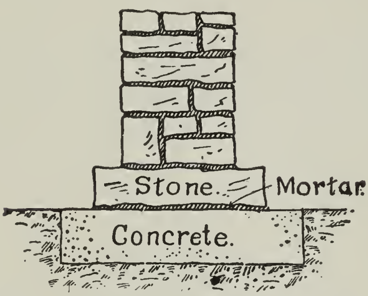

Fig. 53. Concrete and Stone Footing.

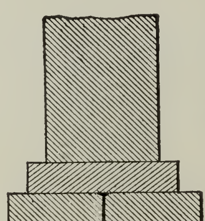

Fig. 54. Two-Course Stone Footing.

For the manner of mixing the concrete see Chapter X. For width of offsets see Article 103.

100. BUILDING LAWS REGARDING CONCRETE FOOTINGS.—The building laws of several of the principal cities agree closely with the New York building laws in their requirements for concrete footings. In New York concrete for footings must consist of at least 1 part of Portland cement to 2 parts of sand and 5

parts of broken stone, and the stone must be of such a size that it will pass through a 2-inch ring. Clean gravel in the same proportions may be substituted for the stone. The footing course must in all cases be at least 12 inches in thickness, and at least 12 inches wider than the bottom width of the wall, or of the piers, columns or posts. Should the projection of the footing be subjected to undue transverse stress, the thickness must be increased so as to safely carry the load. A deviation from the law with regard to the 12-inch thickness may be made, however, at the discretion of the Commissioner of Buildings, where the structure is small or the loads are light.

101. STONE FOOTINGS.—For buildings of moderate height stone footings are generally the most economical, and if they are carefully bedded, answer as well as concrete.

If practicable, the bottom footing course should consist of single stones of the full width of the footing, and the thickness of the stones should be about one-fourth of their width, depending much, however, upon the kind of stone. If stone of sufficient width cannot be obtained, the stone may be jointed under the center of the wall, and a second course consisting of a single stone placed on top, as shown in Fig. 54.

In order that the projection of a stone in a footing course shall have sufficient transverse resistance, the length of the part of the stone beneath the upper course should be at least twice the projection of the stone; that is, a stone in a footing course should not have a projection greater than one-third of its length. If shorter stones than these are used, the projecting courses of the footings are apt to break off, or to be torn from their beds.

It is good practice in the design of stone footing courses to keep the angle between the horizontal and a line drawn through the upper outside edges of the projecting courses not less than 60 degrees, or to make the projection such that it will not be greater than one-half the thickness of the course. Where this rule is followed, the footing is not likely to fail by the cracking or breaking off of the projection.

For light buildings of only one or two stories, used for dwellings or similar purposes, irregular-shaped stones, called "heavy rubble," are generally used, as shown in Fig. 55, which represents a plan of the footing course, the spaces between the larger stones being filled in with smaller stones. Each stone should be laid in cement

mortar and the spaces between the stones solidly filled with mortar and broken stone.

Under heavy buildings the footing stones should be what are called "dimension stones"; that is, roughly squared to certain dimensions. Dimension stones for footings may be obtained from 4 to 8 feet in length, according to the kind of stone. The width of the stones, measured lengthwise of the wall, should be at least 2 feet, or two-thirds the width of the footings.

The best stones for heavy footings are: Granite, bluestone, slate and some hard laminated sandstones and limestones.

102. BEDDING OF FOOTING STONES.—As footing stones are generally very rough, being left as they come from the quarry, they cannot be made to bear evenly on the bottom of trenches without being bedded either in a thick bed of mortar, or, if the soil is sand or gravel, by washing the sand into the spaces by means of a stream of water. As a rule, the only safe way is to specify that the stones shall be set in a thick bed of cement mortar and worked around with bars until they are solidly bedded.

103. OFFSETS.—The projection of the footings beyond the wall, or the course above, is a point that must be carefully considered, whatever be the material of the footings.

If the projection of the footing or offset of the courses is too great for the strength of the stone, brick or concrete, the footing will crack, as shown in Fig. 56.

The proper offset for each course will depend upon the vertical pressure, the transverse strength of the material, and the thickness of the course. Each footing stone may be considered as a beam

TABLE VII.

Safe Offsets for Masonry Footing Courses.

KIND OF FOOTING.	R. IN LBS. PER SQ. IN.*	OFFSET FOR A PRESSURE, IN TONS PER SQUARE FOOT ON THE BOTTOM OF THE COURSE, OF					
		0.5	1	2	3	5	10
Bluestone flagging	2,700	3.6	2.6	1.8	1.5	1.2	.8
Granite	1,800	2.9	2.1	1.5	1.2	1	.7
Limestone	1,500	2.7	1.9	1.3	1.1	.9	.6
Sandstone	1,200	2.6	1.8	1.3	1.0	.8	.5
Slate	5,400	5.0	3.6	2.5	2.2	1.5	1.2
Best hard brick	1,200	2.6	1.8	1.3	1.0	.8	.5
Concrete { 1 Portland, 2 sand, 3 pebbles	150	0.8	0.6	0.4	....	....	....
Concrete { 1 Rosendale, 2 sand, 3 pebbles	80	0.6	0.4	0.3	....	....	....

* Modulus of Rupture, values given by Ira O. Baker in "Treatise on Masonry Construction."

fixed at one end and uniformly loaded, and in this way the safe projection may be calculated.

Table VII gives the *safe offset for masonry footing courses, in terms of the thickness of the course,* computed with a factor of safety of 10.

It should be borne in mind that as each footing course transmits the entire weight of the wall and its load, the pressure will be greater per square foot on the upper courses, and the offsets should be made proportionately less.

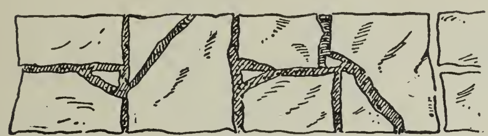

Fig. 55. Plan of Heavy Rubble Footing Course.

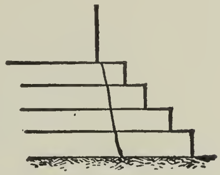

Fig. 56. Footing Crack Caused by Too Great Projection.

104. EXAMPLE OF STONE FOOTING COURSE OFFSETS.—A 4 feet wide footing course of limestone transmits a load of 12 tons per lineal foot or 3 tons per square foot; the thickness of the course is 10 inches. What should be the width of the course above?

Solution.—From the table under the column headed 3 we find the projection to be 1.1 times the thickness, or in this case 11 inches. As we would have the same projection each side of the wall, the stone above may be 22 inches less in width, or 2 feet 2 inches wide. Except in cases where it is necessary to obtain very wide footings it is better not to make the offsets more than 6 or 8 inches, and in the case above it would be better to make the upper footing course 3 feet wide. Most building ordinances require the projection of the footings beyond the foundation wall to be at least 6 inches on each side.

105. BRICK FOOTINGS.—On sandy soils brick foundations and footings may be used when good stone cannot be cheaply obtained. In Denver, Col., where the soil is a mixture of sand and clay, very dry and unaffected by frost, brick foundations have been found to answer the purpose fully as well as stone for two and three-story buildings.

In building brick footings, the principal point to be attended to is to keep the back joints as far as possible from the face of the

work; and in ordinary cases the best plan is to lay the footings in single courses, the outside of the work being laid all headers, and no course projecting more than one-quarter brick beyond the one above it, except in the case of unloaded 9-inch walls. The bottom course should in all cases be a double one. Figs. 57 to 60 show the proper arrangement of the brick in walls from one to three bricks in thickness. If the ground is soft and compressible, or the wall

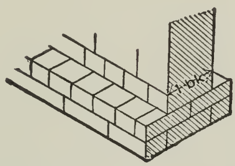

Fig. 57.

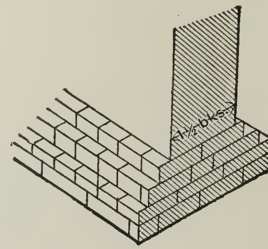

Fig. 58.

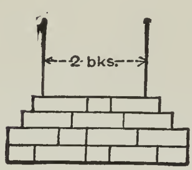

Fig. 59.

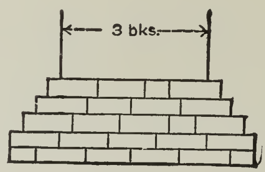

Fig. 60.

Figs. 57-60. Examples of Brick Footings. Proper Arrangement of Bricks.

heavily loaded, the footings should be made wider, as shown in Fig. 61. For brick footings under high walls, or walls that are very heavily loaded, each projecting course should be made double, the heading course above and the stretching course below.

The bricks used for footings should be the hardest and soundest that can be obtained, and should be laid in cement or hydraulic lime mortar, either grouted or thoroughly slushed up, so that every joint will be entirely filled with mortar. The writer favors grouting for brick walls; that is, using thin mortar for filling the inside joints, as he has always found that it gives very satisfactory results.

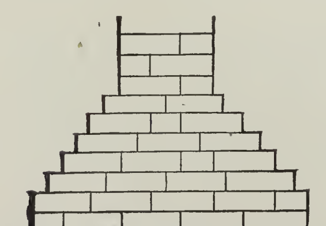

Fig. 61. Wide Brick Footings for Heavy Walls on Compressible Soils.

The bottom course of the footing should always be laid in a bed of mortar spread on the bottom of the

trench, after the latter has been carefully levelled. All bricks laid in warm or dry weather should be thoroughly wet before laying, for, if laid dry, they rob the mortar of a large percentage of its moisture, greatly weakening its adhesion and strength.

106. IMPORTANCE OF CAREFUL CONSTRUCTION OF FOOTING COURSES.—Too much care cannot be bestowed upon the footing courses of any building, as upon them depends much of the stability of the work. If the bottom courses are not solidly bedded, if any seams or vacuities are left in the beds of masonry, or if the materials themselves are unsound, the effects of such carelessness are sure to show themselves sooner or later, and almost always when they cannot be well remedied. Nothing is more apt to injure the reputation of a young architect than to have a building constructed under his direction settle and crack; and he should see personally that no part of the foundation work is in any way slighted.

107. STEPPED BRICK FOOTINGS ON CONCRETE FOUNDATION.—In the construction of footings under brick walls a bed of concrete is commonly used, and the brickwork offsetted from this bed up to the required thickness for the wall. Such stepped-up brick footings, with concrete beds or footings beneath, are shown in Fig. 62 at (*a*) and (*b*). The illustration represents the vertical cross-section of an exterior wall of a building built close to the street or party-line. In the figure, at (*a*), the footing is formed by stepping back each course of brickwork, while at (*b*) the stepping is made at every other course. Either of these methods of building brick footings, with the projections given in the illustration, meets the requirements of the New York building law.

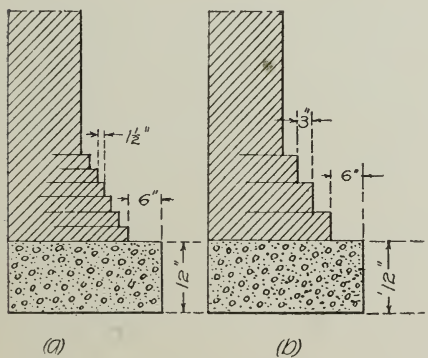

Fig. 62. Offsets of Concrete and Brick Footings Under Outside Walls.

108. INVERTED ARCHES.—Inverted arches are sometimes built under and between the bases of piers, as shown in Fig. 63, with the idea of distributing the weight of the piers over the whole length of the footings. This method is objectionable, first, because it is nearly impossible to prevent the end piers of a series from being

pushed outward by the thrust of the arch, as shown by the dotted line; and secondly, because it is generally impossible with inverted arches to make the areas of the different parts of the foundation proportional to the load to be supported. It is much better to build the piers with separate footings, projecting equally on all four sides and proportioned to the loads they support. The intermediate walls may be supported by steel beams or arches, as preferred.

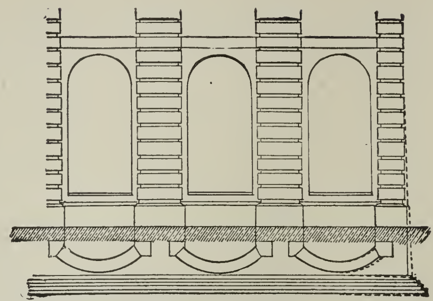

Fig. 63. Illustration of Inverted Arches.

In some instances, however, when building on comparatively soft soils, and where it is impracticable to use spread footings, inverted arches may be advantageously used, especially when it is necessary to reduce the height of the footing to a minimum.

If it is decided to use inverted arches, the foundation bed should be levelled and a footing built over the whole bed to a depth of at least from 12 to 18 inches below the bottom of the arch. Concrete is much the best material for this footing, although brick or stone may be used if found more economical. The upper surface of the footing should be accurately formed to receive the arch, which should be built of hard bricks laid in cement mortar, generally in separate rings or rowlocks, and should abut against stone or concrete skewbacks, as shown in Fig. 64.

It is better to build the arches before putting in the skewbacks, and for the latter 1 to 6 Portland cement concrete possesses special

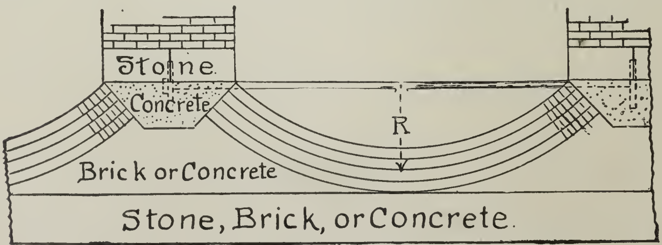

Fig. 64. Details of Footings with Inverted Arches.

advantages, as it can be deposited between the ends of the arches and rammed evenly and simultaneously, giving a solid and uniform bearing against the ends of the arches, and tending to prevent unequal settlement and cracking.

109. Above the concrete skewback a solid block of stone should be placed if it can be readily obtained. The thickness of the arch ring should be at least 12 inches, and heavy iron plates or washers should be set in the middle of the concrete skewbacks and connected with iron or steel rods, to take up the thrust of the end arches. The "rise" of the arch, or distance R, Fig. 64, should be equal to from $\frac{1}{4}$ to $\frac{1}{6}$ of the span. The sectional area of the arch should equal the result obtained by the following formula:

$$\text{Section of arch in sq. ins.} = \frac{\text{Total load on arch (in lbs.)} \times \text{span}}{8 \times R \times 10} \quad (7)$$

For wrought-iron tie-rods

$$\text{Section of rods in sq. ins.} = \frac{\text{Total load on arch (in lbs.)} \times \text{span}}{8 \times R \times 850} \quad (8)$$

For steel tie-rods

$$\text{Section of rods in sq. ins.} = \frac{\text{Total load on arch} \times \text{span}}{8 \times R \times 1050} \quad (9)$$

the span being measured in *feet,* and the distance R in *inches.*

The load on the arch will be equal to the span multiplied by the pressure per *lineal foot* imposed on the soil. The latter will be obtained by dividing the load on the piers by the distance between centers of piers.

110. EXAMPLE IN CALCULATION FOR INVERTED ARCH FOOTINGS.—It is desired to use inverted arches between the piers of a three-story building, resting on a soil whose bearing power cannot be safely estimated at over 3,000 pounds per square foot. The piers are of stone, 4 feet long, 22 inches thick, and 14 feet apart on centers. Each pier supports a total load of 98,000 pounds. What should be the sectional area of the arch, and of the rods in the end spans?

Solution.—The span of the arch will be 10 feet, and the distance R about one-fifth of 10 feet, or 24 inches. The load per lineal foot on the soil will equal 98,000÷14, or 7,000 pounds. The footing under the arch must therefore be 2 feet 4 inches wide to reduce the pressure to 3,000 pounds per square foot. The width of the arch

itself we will make 22 inches, or two and one-half bricks. The total load on the arch will equal $10 \times 7{,}000$, or 70,000 pounds.

The sectional area of the arch must therefore equal

$$\frac{70000 \times 10}{8 \times 24 \times 10} \text{ or } 354 \text{ square inches.}$$

As the width is 22 inches, the depth must equal $354 \div 22$, or 16 inches, which will require four rowlocks or rings.

The sectional area of the ties must equal, for wrought-iron,

$$\frac{70000 \times 10}{8 \times 24 \times 850} \text{ or } 4.3 \text{ square inches.}$$

In this case it will be better to use two rods of 2.15 square inches in area, or two 1¾-inch rods.

All cast-iron work in the foundation should be coated with hot asphalt, and the rods should be dipped in linseed oil while new and hot and afterward painted one heavy coat of oxide of iron or red lead paint.

2. FOUNDATION WALLS

111. GENERAL DESCRIPTION.—This term is generally applied to those walls which are below the surface of the ground, and which support the superstructure. Walls whose chief office is to withhold a bank of earth, like those around areas, are called retaining-walls.

Foundation walls may be built of stone, brick or concrete, the first being the most common. Brick walls for foundations are only suitable in very dry soils, or in the case of party-walls, where there is a cellar or basement each side of them.

As the method of building brick foundations is the same as for any brick wall, it will not be described here, but will be taken up in the chapter on Brickwork. For concrete walls see Chapter X.

112. STONE WALLS.—The principal details to be watched in building a stone foundations wall are the character of the stone and mortar, and the bonding, filling of voids and pointing.

The best stones for foundations are granites, compact sandstones, slates and blue shale. The less porous the stone the better it will stand the dampness to which it must be subjected. As a rule laminated stones make the best walls, as they split easily and give flat and parallel beds. If the only stones to be had are boulders

or field-stones, they should be split so as to form good bed-joints. Cobble or round stones should never be used for building foundation walls, and for all buildings exceeding three stories in height, block stone or the best qualities of laminated stone should be used.

The mortar for foundation walls below the grade line should be made either of Portland cement, natural cement, or hydraulic lime, with coarse sand; while above grade good common lime, or lime and cement, may be used.

The usual practice in building foundations is to use the stone just as it is blasted from the quarry; or, if the building is built on a ledge, the material from the foundation itself, the stone receiving no preparation other than a breaking up with a sledge-hammer, and the squaring of one edge for the face. Too great irregularity and unevenness is overcome by sparing the use of the stone-hammer and by varying the thickness of the mortar joint in which the stones are bedded. The strength of the wall, therefore, depends largely upon the quality of the mortar used.

The wall should be levelled off about every 2 feet, so as to form irregular courses, and the horizontal joints should be kept as nearly level as possible.

When block stones are used they are generally from 18 inches to 2 feet thick and the full width of the wall. They are commonly roughly squared with the hammer, and but little mortar is used in the wall. Only in a few localities, however, are such stones obtainable at a price that will permit of their use, so that as a rule stones split from a ledge and called "rubble" are the materials with which the architect will have to deal.

113. BONDING.—Aside from the quality of the stone and mortar, the strength of a rubble wall depends upon the manner in which it is bonded or tied together by lapping the stones over each other. About every 4 or 5 feet in each course a bond-stone should be used; that is, a stone that will go entirely through the wall, and, by its friction on the stones below, hold them in place. A stone that goes three-fourths of the way through the wall is called a three-quarter bond. It is customary to specify that there shall be at least one through-stone in every 5 or 10 square feet of the wall, depending upon the character of the stone and nature of the building. Fig. 65 shows a portion of wall built of square or laminated stones, with through bond-stones at *B B*, and three-quarter

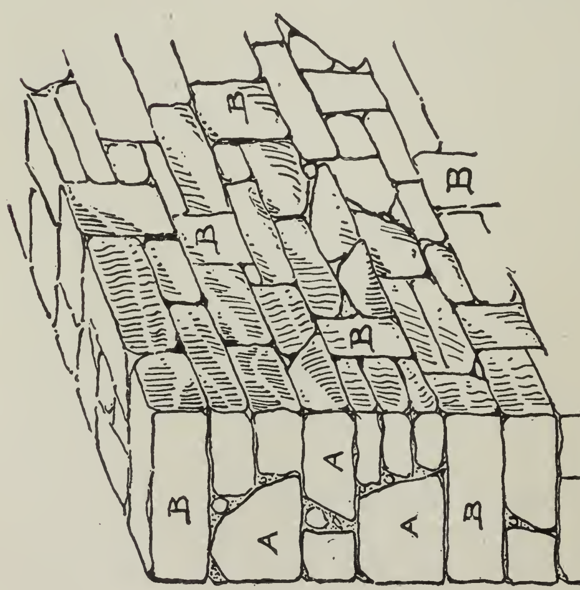

Fig. 65. Rubble Stone Wall Showing Bond-Stones.

Fig. 66. Rubble Stone Wall. Too Long Vertical Joint.

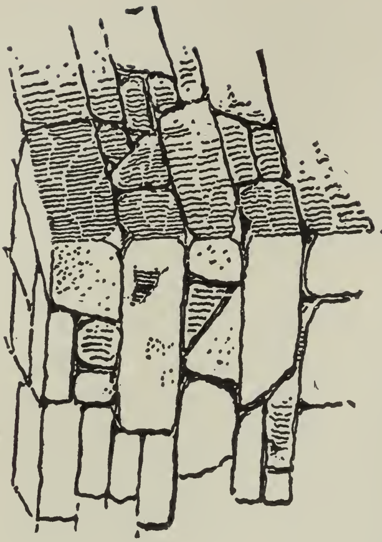

Fig. 67. Rubble Stone Wall. Long Angle-Stones.

bond-stones at *A A*. A good three-quarter bond is nearly equal in strength to a through-bond, and when the character of the stone will permit of the wall being built largely of flat stones extending two-thirds of the way through the wall, it will not be necessary to use more than one through-stone to every 10 square feet of wall. No stone should be built into the face of a wall with a depth less than 6 inches, although stone-masons will often set a stone on edge, so as to make a good face and to give the appearance of a large stone, when it may be only 3 inches thick. All kinds of stones should always be laid so that their natural bed, or splitting surface, will be horizontal. It is also important that the stones shall break joint longitudinally, as in Fig. 65, and not have several vertical joints over each other, as at *A A,* Fig. 66. The angles of the foundation should be built up of long stones, laid alternately header and stretcher, as shown in Fig. 67 The largest and best stones should always be put in the corners, as these are usually the weakest parts of a wall.

114. FILLING VOIDS.—All stones, large and small, should be solidly bedded in mortar, and all chinks or interstices between the large stones should be partially filled with mortar and then with small pieces of stone, or spalls, driven into the mortar with the trowel, and then smoothed off on top with mortar.

Many masons are apt to build the two faces of a wall with long, narrow stones and fill in between with dry stones, throwing a little mortar on top to make it look well.

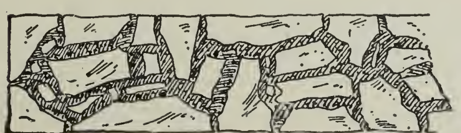

Fig. 68. Section of Poorly Built Rubble Stone Wall.

Fig. 69. Section of Properly Built Rubble Stone Wall.

A horizontal section through such a wall would appear as shown in Fig. 68. A wall of this kind would require but little loading to cause the outside faces to bulge, owing to the lack of strength in its middle portion. The way in which a wall of irregularly shaped stones should be built in order to be as strong as possible is shown in Fig. 69.

A wall of this kind requires no more stone than the other, but requires more *lifting* and a little more work with the hammer, and

these appear to be the real reasons why better workmanship does not oftener result.

115. WINDOW OPENINGS.—If there should be a window or door opening in the foundation wall, as in Fig. 70, the stones just below the opening should be laid so as to spread the weight

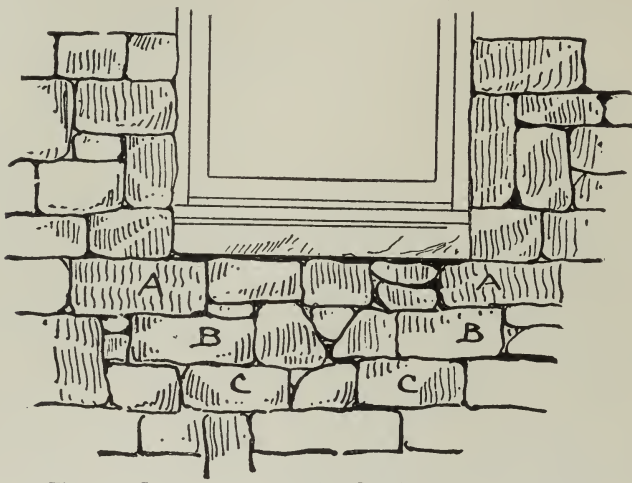

Fig. 70. Stones Under Window Opening. Proper Method.

of the wall under it, as shown by the stones *A B C*. If any great weight is to come upon the foundation it is better not to build the window sills into the wall, but to make their length just equal to the width of the opening. These are called "slip-sills," and there is no danger of their breaking by uneven settlement.

Occasionally some part of the foundation wall of a building goes down much lower than the adjoining portions, and, as there is almost always a slight settlement in the joints of a wall, unless laid in cement the deeper wall will naturally settle more than the other, and thus cause a slight crack. This can be avoided by building the deeper wall of larger stones, so that there will be no more joints than in the other wall, or by making thin joints and using cement mortar.

116. THICKNESS OF FOUNDATION WALLS.—The thickness of a foundation wall is usually governed by that of the wall above, and also by its own depth.

Nearly all building regulations require that the thickness of a foundation wall, to a depth of 12 feet below the grade line, shall be 4 inches greater than the wall above for brick and 8 inches

greater for stone; and that for every additional 10 feet, or part thereof in depth, the thickness shall be increased 4 inches. In all large cities the thickness of the walls is controlled by law. In cases where the thickness is not so governed the following table will serve as a fair guide:

TABLE VIII.

PROPER THICKNESS FOR FOUNDATION WALLS.

HEIGHT OF BUILDING.	DWELLINGS, HOTELS, ETC.		WAREHOUSES.	
	BRICK.	STONE.	BRICK.	STONE.
	Ins.	Ins.	Ins.	Ins.
Two stories......................	12 or 16	20	16	20
Three stories....................	16	20	20	24
Four stories.....................	20	24	24	28
Five stories.....................	24	28	24	28
Six stories......................	24	28	28	32

Only block stone, or first-class rubble, with flat beds, should be used in foundations for buildings exceeding three stories in height. The footings should be at least 12 inches wider than the width of the walls. (See Article 98.)

In heavy clay soils it is a good idea to batter the walls on the outside, making the wall from 6 inches to a foot thicker at the bottom than it is at the top, and plastering the outside with cement. (See Fig. 6, Article 10.)

3. RETAINING-WALLS

117. GENERAL DESCRIPTION.—A retaining-wall is one that is built to hold up a bank of earth, which is deposited behind it after it is built. The term *breast-wall* or *face-wall* is used for a similar structure built to prevent the fall of earth which is in its undisturbed natural position, but in which a vertical or inclined face has been left after the excavations. Retaining-walls also differ from foundation walls, in that the latter support superstructures whose weights are generally sufficient to overcome the thrust of the earth against the walls. Retaining-walls depend upon their own stability to resist earth-pressure.

Area walls generally serve as retaining-walls, but as they are usually braced by arches or cross walls from the building wall, they do not require the same thickness as a retaining-wall proper.

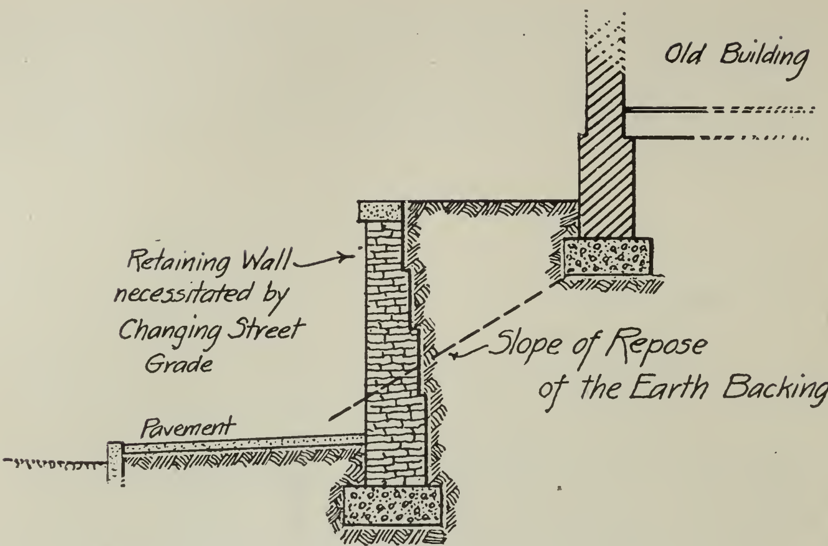

Fig. 71. Retaining-Wall and Foundation Wall. Poor Construction.

Several theoretical formulas have been proposed by writers on engineering subjects for computing the necessary thickness and most economical section for retaining-walls; but so many varying conditions enter into the designing of such walls, such as the character and cohesion of the soil, the extent to which the bank has been disturbed, the manner in which the material is filled in against the wall, etc., that little confidence is placed in these theoretical formulas, and engineers appear to be guided rather by empirical rules.

118. MANNER OF FAILURE.—Retaining-walls may fail in any one of several ways; by tipping or overturning; by bulging; or by the sliding of the footings. The first is the most common form of failure and is caused by the pressure of the earth backing, overturning the wall about the outside edge of the footing or wall. A retaining-wall may fail also by bulging, caused by filling in back of the wall while the masonry is still green; by water penetrating back of the wall and freezing; or by a change in the nature of the soil due to heavy rains. While the failure of a retaining-wall by the sliding of the footings is not frequent, it has sometimes occurred where it has been sufficiently heavy to resist overturning, and where the footings have been built on unstable soil, such as slippery clay, or other unctuous material.

Retaining-walls which hold back earth embankments liable to

vibration from passing trains or from heavy street traffic are more likely to fail than walls not subjected to such vibration, and should be made from 25 per cent to 50 per cent heavier. The foundation walls and area walls of buildings are frequently required to act as retaining-walls along railroad sidings and should be carefully designed to meet this condition.

The failure of a retaining-wall has been caused by the overloading of the earth embankment or the backing which it supports. A condition likely to cause failure is shown in Fig. 71, where the footing of an adjacent building is not down to the level of the footing of the retaining-wall required by the changing of the grade of the street.

119. DESIGN AND CONSTRUCTION.—The cross-section that appears to be generally approved for retaining-walls, particularly in engineering work, is shown in Fig. 72.

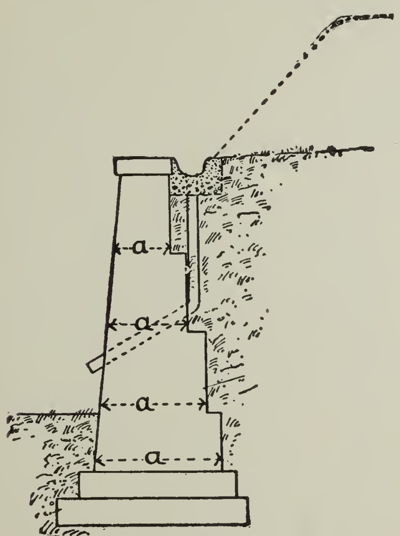

Fig. 72. Retaining-Wall. Generally Approved Section.

The wall may be either built plumb, as shown, or inclined toward the bank. The latter method is generally considered to result in greater stability, although it is open to the objection that the water which runs down the face of the wall is apt to penetrate into the inclined joints.

Retaining-walls should be built only of good hard split or block stone,* laid in cement mortar and carefully bonded, to prevent the stones from sliding on the bed-joints.

The thickness of the wall at the top should be not less than 18 inches, and the thickness, *a*, just above each step should be from ⅓ to ⅖ of the height from the top of the wall to that point.

If the earth is banked above the top of the wall, as shown by the dotted line, Fig. 72, the thickness of the wall should be increased. A thickness equal to one-half of the height will generally

* Or of Portland cement concrete with metal reinforcements.

answer for a height of embankment equal to one-third the height of the wall.

The outer face of the wall is generally battered, or sloped outward, about 1 inch to the foot,

Stepping the wall on the back increases the stability by bonding it into the material behind and by increasing the weight by the weight of the soil resting upon the steps.

Care should be used in filling in back of a retaining-wall, for the stability varies considerably with the method employed. The stability of the wall is increased if the earth is well rammed in layers inclined down from the wall, whereas if the earth is filled in in layers sloping up toward the wall, it must be made stronger to resist the full pressure of the earth.

If built upon ground that is affected by frost or surface water, the footings should be carried sufficiently below the surface of the ground at the base of the wall to insure against heaving or settling.

If the ground back of the wall slopes toward the wall a cement gutter should be formed behind the coping and connected with a drain pipe to carry off the surface water. The back of the wall and the tops of the steps should be plastered with cement to the depth of at least 3 or 4 feet.

120. REINFORCED CONCRETE RETAINING-WALLS.—Retaining-walls are now frequently constructed of reinforced concrete, and are built as shown in the section in Fig. 73. Such walls depend for their stability rather upon the wide reinforced concrete base than upon the dead weight of the concrete. As a rule, reinforced concrete retaining-walls are not more than 8 inches in thickness at the top and 18 inches at the bottom. The concrete of the retaining-wall is reinforced so as to resist the pressure of the earth backing, by providing sufficient transverse strength

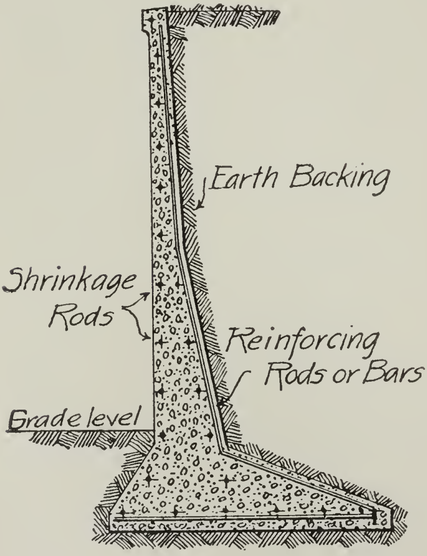

Fig. 73. Section of Reinforced Concrete Retaining-Wall.

or resistance to bending between the wall and the footing; and the width of the footing, together with the weight of the earth backing upon it, adds additional stability to the wall. The footing is also reinforced sufficiently to prevent its failing by transverse or bending stresses. In addition to the reinforcing rods, the wall is usually provided with shrinkage rods running horizontally and placed about 2 feet on centers. They are made of from ¼-inch to ½-inch round or square bars. The concrete used in such walls is generally made of a 1, 2½ and 5 mixture of cement, sand or gravel, and broken stone respectively. The exposed face of the wall is molded smooth by the use of planed boards, neatly matched in the construction of the forms; and is afterwards washed down with a cement wash put on with a soft brush, or is rubbed with carborundum blocks dipped in a cement paint or wash.

4. AREA WALLS

121. GENERAL DESCRIPTION.—Areas are often excavated outside the foundation walls of buildings to give light or access to the basement, and require surrounding walls to retain the earth and present a neat appearance.

Such walls should be built of stone, as stone walls offer greater resistance, when the mortar is green, to sliding on the bed-joints than is offered by brick walls.

In making the excavation the earth should be disturbed as little as possible, and in filling against the walls the soil should be deposited in layers and well tamped, and not dumped in carelessly. Either the filling should be delayed until the mortar has had time to harden, or the walls should be well braced.

Area walls are commonly built like foundation walls with a uniform thickness of about 20 inches for a depth of 7 feet. If more than 7 feet in height the walls should have a batter on the area side and should be increased in thickness at the bottom, so that the average thickness will be at least one-third of the height, unless the walls are braced by arches, buttresses or cross walls.

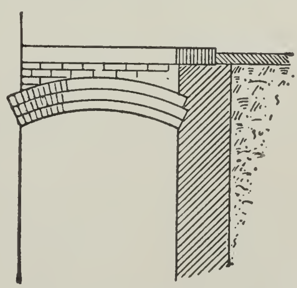
Fig. 74. Area Wall Braced by Arch.

Area walls sustaining a street or alley should be made thicker than those in an open lot.

When an area wall is more than 10 feet long it is generally practicable to brace it from the basement wall by arches thrown across from one wall to the other, as shown in Fig. 74. When this cannot be done the wall should be stiffened by buttresses about every 10 feet.

5. VAULT WALLS

122. GENERAL DESCRIPTION.—In large cities it is customary to utilize the space under the sidewalk for storage or other purposes. This necessitates a wall at the curb line to sustain the street and also the weight of the sidewalk.

Where practicable, the space should be divided by partition walls about every 10 feet, and when this is done the outer wall may be advantageously built of hard bricks in he form of arches, as shown in Fig. 75.

The thickness of the arches should be at least 16 inches for a depth of 9 feet, and the "rise" of the arch 1/6 of the span.

If partitions are not practicable, each sidewalk beam may be supported by a heavy I-beam column, with either flat or segmental arches between, as shown in Fig. 76.

This latter method is more economical of space than any other, and where steel is cheap is about as economical in cost.

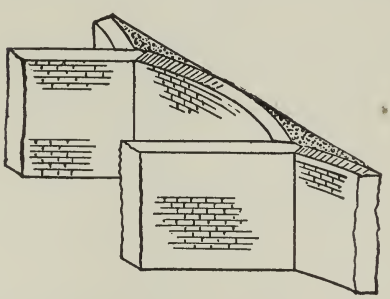

Fig. 75. Arched Sidewalk Vault Walls with Partition Walls.

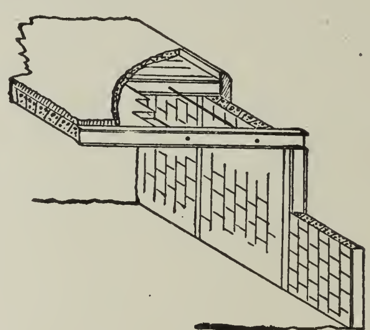

Fig. 76. Sidewalk Vault Walls with I-Beam Columns and Flat Arches.

6. SUPERINTENDENCE OF FOUNDATION WORK.

123. THE FOOTINGS IN GENERAL.—The first work on the foundations is the placing of the footings.

If they are of concrete, an inspector should remain on the work during the working hours to see that every batch of concrete is mixed exactly as specified, that the aggregates are broken to the

proper size and that the cement is all of the same brand and in good condition. There is no building operation that can be more easily "skimped" without detection than the making of concrete, and the only way in which the architect can be sure that his specifications have been strictly followed is by keeping a reliable representative constantly on the ground. The inspector should see also that the concrete is put in to the full thickness shown on the drawings, and that it is levelled and tamped every 6 inches in depth.

When water is encountered in the trenches, it should be collected in a shallow hole and removed by a pump or drain, as explained in Article 35. Very often, when the foundation rests on the top of a ledge, underlying gravel or clay, running water will be encountered in the trenches in too great a volume to be readily removed. In this case, the flow of water should be intercepted by a drain and cesspool, and a tight drain carried from the latter to a sewer or to a dry well below the foundation of the building.

Concrete footings for piers not more than 4 or 5 feet square may be built, where there is running water, by making large bags of oiled cotton, sinking them in the pit and filling the concrete into them immediately. The water will probably rise around the bags, but if the latter keep the water away from the concrete until the cement has had time to set, they will have answered their purpose. Water does not injure concrete, nor mortar made of cement, after they have begun to harden; but if freshly-mixed concrete is thrown into water, the latter separates the cement from the sand and aggregates, the cement mixing with the water and floating away, while the sand and stone drop to the bottom. For this reason concrete should never be thrown into trenches containing water.

124. DETAILS OF FOOTINGS, WALLS, MATERIALS, ETC.—If the footings are of stone the presence of water does not do as much harm, provided it can be drained so as not to attain a greater depth than 3 or 4 inches. Sometimes the bottom of a wall is used as a drain for collecting the seepage water, and the trench is partially filled with stones laid without mortar, as explained in Article 10.

For heavy buildings, however, the footings should be solidly bedded in cement mortar when the trenches are reasonably dry; and when this it not the case, in sand or fine gravel. An irregular footing stone can often be bedded more solidly by piling fine sand around it and then washing the sand under the stone with water,

than it can by laying it in cement mortar. The former method, however, takes more time, and is seldom employed when mortar can be used with as good results.

As stated in Article 105, too much care cannot be bestowed upon the footing courses of any building, and there is no portion of it that needs closer inspection than the footings and foundation.

Before the masons commence actual operations the architect should inspect all materials that have been delivered, to see that they are of the kind and quality specified.

The mortar, together with the sand, cement or lime, should be particularly examined, to see that it has the proper proportions of cement or lime, and is well worked; that the cement or lime is fresh and of the kind or brand specified; and that the sand is clean and sharp. The building of the foundation wall should also be carefully watched to see that the wall is well tied together with plenty of three-quarter and through bond-stones, and that the inside is solidly filled with stone and mortar.

The superintendent must also examine the wall occasionally to see that it is built straight and plumb, and that the general bed of the courses is horizontal.

When inspecting stonework already built, but which has not had time for the mortar to harden, a light steel rod, about $^3/_{16}$ inch in diameter and 4 or 5 feet long, will be found useful. If the rod can be pushed down into the center of the wall more than 18 inches or 2 feet in any place it shows that the stones have not been lapped over each other, and if this can be done in several places the inspector should order the wall taken down and rebuilt. The rod will also indicate to a considerable extent whether or not the stones in the center of the wall have been well bedded, for if this is not the case, they will rock or tip when struck with the rod.

The inspection of a foundation wall cannot be too thorough, as there is nothing that causes an architect so much trouble as settlements in the foundations of his buildings.

125. FILLING IN.—In buildings, in which the cellar floor is 6 feet or more below the ground level, the trenches behind the walls should not be filled in until the floor joists are on and the walls built 6 feet or more above them, or until the walls are solidly braced with heavy timbers, as otherwise the walls may be sprung by the pressure of loose dirt. In heavy clay soils it is a good idea to fill in back of

the walls with coarse gravel, stone spalls and sand, as frost will not "heave" them as it does clay.

126. HOLES FOR SOIL-PIPES AND SUPPLY PIPES.—In thick walls built of heavy stone, the architect should locate the position of the soil-pipes and supply pipes, and see that openings are left in the proper places for the pipes to pass through them.

7. DAMPNESS IN CELLAR WALLS

127. GENERAL CONSIDERATIONS.—In many localities it is necessary to guard against dampness in cellar walls, particularly in buildings where the basement is used for living-rooms or for storage. There are several devices for preventing moisture from entering walls, some being applications on the outside and others being constructive devices.

Where surface water only is to be provided against, and the ground is not generally saturated with water, coating the outside of the wall with asphalt or Portland cement will, in most cases, prove a preventative against dampness.

128. DAMP-PROOFING CELLAR WALLS.—Asphalt, applied while boiling hot to the outside of a wall, is generally considered a lasting and durable coating. To insure perfect protection, the wall should be built as carefully as possible, the joints well pointed and the whole allowed to dry before the coating is applied. The asphalt should be applied in two or more coats and carried down to the bottom of the footings.

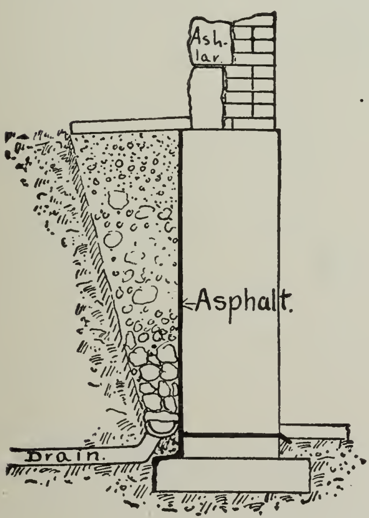

Fig. 77. Cellar Wall, Damp-Proofed and Drained.

If the soil is wet and generally saturated with water, moisture is apt to rise in the wall by absorption from the bottom. To prevent this, two or three thicknesses of asphaltic felt, laid in hot asphalt, should be bedded on top of the footings, just below the basement floor, as shown by the heavy line, Fig. 77.

Portland cement may be used in place of asphalt if the ground is not exceedingly damp; but if it is often saturated with water, asphalt should be used. The objections to Portland cement are that it is easily fractured by any settlement of the

walls, and being to some degree porous, suffers from the action of frost.

Common coal-tar also is often used for coating cellar walls. It answers the purpose very well for a time, but gradually becomes brittle and crumbles away.

129. WATERPROOFING BASEMENTS.—It is frequently necessary in cities to construct dry basements in those localities in which water permeates the soil to within a few feet of the sidewalks.

In such cases it is necessary not only to make the walls and floors waterproof, but also to give sufficient thickness to the floors that the buoyant force of the water will not cause it to break through.

To make the cellar water-tight, its entire area should be covered with concrete from 3 to 6 inches thick, after the footings of the walls and piers are in, so that it will be level with the top of the footings. A narrow course of brick or stone should then be laid along the middle width of the footings to form a break, as shown in Fig. 78. Upon the top of the footings three thicknesses of tarred felt or burlap should then be mopped with hot asphalt, the felt being allowed to project 6 inches on each side. A similar layer of felt and asphalt should be laid over the footings of all piers, engine foundations, etc., and allowed to project at least 6 inches on all sides.

After the exterior walls are completed, and before "filling in," the projecting felting should be turned up against them and mopped with hot asphalt; and the entire outside surfaces to the sidewalk line should be covered with three thicknesses of felt laid breaking joints in hot asphalt and overlapping the felt coming through the walls. For further protection this covering is also frequently plastered with 1 to 2 Portland cement mortar.

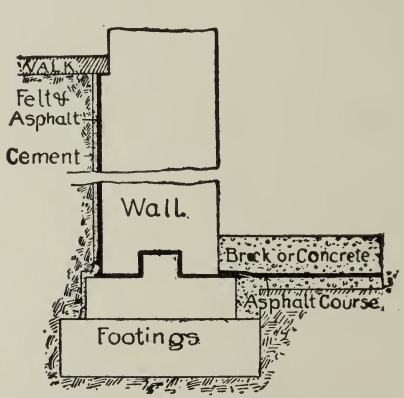

Fig. 78. Water-Proofed Basement Wall.

Before the completion of the building the entire cellar floor, also, should be covered with felt in hot asphalt, laid in at least three thicknesses, breaking joint and overlapping the felt first laid. On the top of the felt thus laid there should then be laid Portland

cement concrete at least 1 inch thick for each 3 inches in depth of the water above the level of the cellar bottom, with a minimum depth of 6 inches.

The following description of the waterproofing of the basement of the *Herald* building, in New York City, is given as an actual example of the above method:*

In this building the printing presses are placed in the basement, and great pains were taken to exclude moisture below grade. The footings and outside basement walls were covered with four-ply burlap mopped on solid, commencing at the inner edge of sidewalk and back over top of vault and down the outside of the wall to the bottom of the same, thence through the wall and turned up against same for connection to the waterproof course.

Beneath the surface of the entire basement, including floor of vaults, the best four-ply roofing felt was mopped on solid, and similar material was used in connection with all piers, extending in each case through the entire thickness of the pier and beneath the entire surface of foundations for boilers and machinery.

The felt was securely lapped and turned up around all walls. Above the felt 4 inches of concrete was laid in the basement and 16 inches in the boiler room.

If less expensive, hard bricks laid in cement mortar and at least three courses in thickness, may be used instead of the concrete above the felt.

130. CONSTRUCTIVE DEVICES FOR DAMP-PROOFING FOUNDATION WALLS.—Of the constructive devices, the simplest is to make the excavation about 2 feet larger each way than the building, so that there will be about a foot or 10 inches between the bottom of the bank and the wall, as shown in Fig. 77. A V-shaped tile drain should be placed at the bottom of these trenches after the walls are built and connected with a horizontal drain, carried some distance from the building.

The trenches should then be filled with cobbles, coarse gravel and sand. If the top, for a distance of about 2 feet from the building, is covered with stone flagging or cement, it will assist greatly in keeping the walls dry.

By draining the soil in this way, and by also coating the walls with asphalt or concrete, perfectly dry walls will in most cases be insured.

For greater protection of the basement from dampness, the basement walls should be lined with a 4-inch brick wall with an air

* From the *Engineering Record*, July 1, 1893.

space between the main wall and the lining; or an area should be built all around the outside walls.

8. WINDOW AND ENTRANCE AREAS

131. WINDOW AREAS.—These features, although not strictly parts of the foundations, are intimately connected with them, and are generally included in the same contract.

The thickness and bracing of area walls has already been considered (see Article 121). The materials and workmanship of the walls should be the same as in the foundation walls.

Window areas intended for light and ventilation should be of ample size, so as not to obstruct the light more than necessary.

For small cellar windows sunk not more than 2 feet below the grade line, semi-circular areas with 9-inch brick walls give the greatest durability at the least expense. If an area is 3 or 4 feet deep, and as many in length and width, the thickness of its walls should be not less than 12 inches for brick and 18 inches for stone.

Area walls should be coped with stone flagging, set in cement, the edge of the flagging projecting 1 inch over the faces of the walls. If flagging cannot be obtained without great expense the top of the walls should be covered with 1 to 1 Portland cement mortar, about ¾ of an inch thick. Freestones and all porous stones are not suitable for area or fence copings.

An area may be drained as follows: The bottom of the area should be carried at least 6 inches below the window sills and should be formed of stone flagging or of bricks laid in cement. Beneath the bottom a small cesspool or sand-trap, about 8 inches square, should be built, which should be connected by a 3-inch drain pipe with the main drain. A cast-iron strainer or drain-plate should be set over the cesspool, flush with or a little below the paving, so that it can be readily removed and the cesspool cleaned.

Where the soil is of gravel or of a sandy nature, a dry drain may be used for an area at little expense. It consists of a vertical piece of salt-glazed tile sewer pipe carried from the cement bottom of the area to a point below the bottom of the footings. The lower end is left open and the upper end is either open or closed with a perforated cover. The bottom of the area is graded to the drain, and the surface water is carried away by the pipe and allowed to seep into the soil below the footings, thus causing no damage.

The footings of the area walls should be started as deep as the bottom of the cesspool, both being below the frost line.

132. ENTRANCE AREAS.—All area steps, when practicable, should be of stone, or of stone and brick combined.* When the soil is hard and compact and not subject to heaving by frost, a short

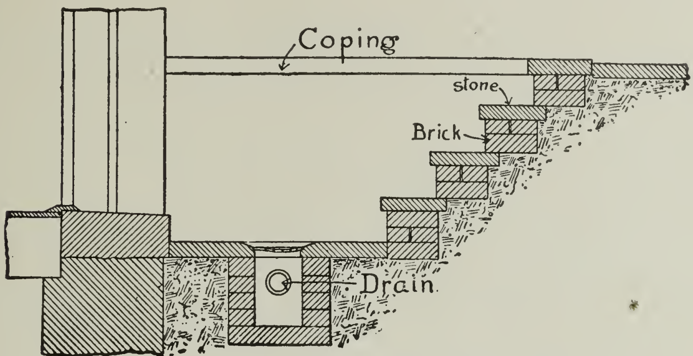

Fig. 79. Entrance Area. Stone-and-Brick Steps.

run of steps may be economically built by shaping the earth to the rake of the steps and building them directly on the earth, laying two courses of bricks, in cement, for the risers, and covering them with 2-inch stone treads, as shown in Fig. 79. All parts of the steps

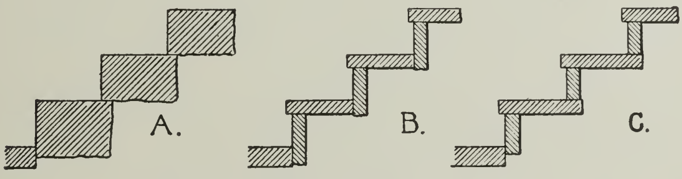

Fig. 80. Sections Through Area Steps.

should be set in cement, and well pointed, and the ends of the treads should be built into the side walls.

If an area is 6 feet or more in depth, or if the soil is sandy or a wet clay, then it must be excavated beneath the steps and entirely surrounded by a wall. The steps may be formed of 2-inch stone risers and treads, or of solid stone, the ends in either case being supported by the side walls. If of solid stone the front of each step should rest on the back of the stone below it, as shown at *A*, Fig. 80. If built of treads and risers they may be arranged

* Or of reinforced concrete (see Chapters IX and X.)

as shown at either *B* or *C*. The arrangement shown at *B* is stronger than that shown at *C*.

If the steps are more than 5 feet long a bearing wall or iron string should be built under the middle of the steps.

Stone steps should always be pitched forward about ⅛ of an inch in the width of the tread.

In many localities plank steps, supported on plank strings, will last for a long time if the ground is excavated below them and the area walled up all around, and when they decay it is a small matter to replace them.

The platform at the bottom of the steps should be of stone or brick, set at least 4 inches below the sill of the door giving entrance to the building, and should be provided with cesspool, plate and drain, as described in Article 131.

All outside stone steps, fence coping, etc., should be set on a foundation carried at least 2 feet below grade, and in localities affected by frost below the freezing line.

9. PAVEMENT VAULTS

133. CONSTRUCTION OF VAULTS UNDER SIDEWALKS.—Vaults are often built under entrance steps and porches, the walls of the vaults forming the foundations for the steps and platforms. The roofs of the vaults are generally formed of brick arches, two rowlocks in thickness, with the stone steps set in cement mortar on top of the arches.

Vaults under sidewalks may be either arched over with brick, the top of the arches levelled off with sand, cinders or concrete, and the sidewalks laid thereon, or the sidewalks themselves, if of large stone flags, may be made to form the roofs of the vaults. In the latter case the joints of the stone slabs are closely fitted and often rebated, then calked with oakum to within about 2 inches of the top and the remaining space filled with hot asphalt or asphaltic mastic. This makes a tight job for a time, but in the course of two or three years the joints need to be cleaned out and refilled.

Any form of fire-proof floor construction may also be used for covering sidewalk vaults and a cement sidewalk may be finished on top of it. Cement makes probably the best walk and the most durable construction, with a comparatively slight thickness.

In San Francisco it has been customary to build the sidewalks of cement, with steel tension-bars or cables imbedded in the bottom,

so that the same construction answers both for the walk and for the covering of the vault.

If brick arches covered with sand and a stone or brick pavement are used, their tops should be covered with hot asphalt.

134. MUNICIPAL REGULATIONS REGARDING VAULTS.—In many cities the building regulations will not permit vaults to be extended under sidewalks unless certain restrictions are complied with. Generally vaults may be built out to what is known as the "area-line," usually 4 or 5 feet from the building-line, but even then there is sometimes a charge made for this privilege. Where vaults are permitted to be built out to the curbs a considerable fee is charged by some cities, amounting in some cases to as much as twenty-five dollars a running foot. It is usual also, where vaults extend to the curb line, to restrict their height, keeping their roofs 4 or 5 feet below the pavement.

These requirements are made by some municipalities in order to provide against interference with underground service wires, and other city installations.

10. PAVEMENTS AND SIDEWALKS

135. GENERAL CONSIDERATIONS.—Although these do not come under the heading of foundations they are more nearly related to that class of work than to any other, and may therefore be described here.

Pavements may be made either of thin slabs of stone, called flagging, of concrete, finished with Portland cement, or of hard bricks made especially for the purpose.

When large slabs of stone can be economically obtained, they make, in the long run, the most economical and satisfactory pavements.

Smoother pavements may be made with cement. They are practically imperishable; but should there ever be occasion to cut through them, or to change the grade, the cement and concrete must be destroyed, while the stone flagging can be taken up and relaid, either in the same place or somewhere else. A stone sidewalk can be also be repaired more easily than either of the others.

Stone Pavements.—As a rule only stones that split with comparatively smooth and parallel surfaces can be economically used for pavements; for, if the surface of the stone has to be dressed,

it will generally be more economical to use concrete and cement or hard bricks.

For yards and areas, flagging from 2½ to 3 inches thick is commonly used, the edges of the stones being trimmed so that they will be perfectly rectangular, and the joints between them straight and from ⅛ to ⅜ inch in width.

The stones should be laid on a bed of sand not less than 2 inches thick, and the edges should be bedded in cement, as shown in Fig. 81, extending 3 or 4 inches under them. On completion the joints should be thoroughly filled with 1 to 1 cement and fine sand, and struck smooth with the trowel.

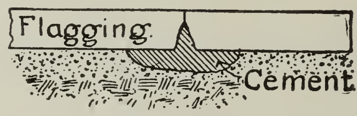

Fig. 81. Section Through Stone Pavement.

In localities where the soil is dry and not affected by frost, as in Colorado, New Mexico, etc., the cement is generally omitted entirely, the stones being simply bedded in sand and the joints filled with fine sand.

This answers very well in those localities; but since, after a time, grass and weeds commence to spring up through the joints of pavements in yards and private walks, for first-class work, bedding in cement should be specified.

Stone sidewalks are generally laid on beds of sand, with the joints in the better class of work bedded in cement. The stones, when 5 feet long, should be at least 3 inches thick, and when 8 feet long, 5 or 6 inches thick. The best sidewalks are laid in one course, unless exceptionally wide.

In localities where the ground is affected by frost, as it is in most of the Northern States, the stones, if merely laid on beds of sand, are sure to become displaced and out of level within one or two years. To prevent this, flagging stones, at least in front of business buildings, should have a solid support at each end.

Fig. 82 shows the manner in which this is generally provided,

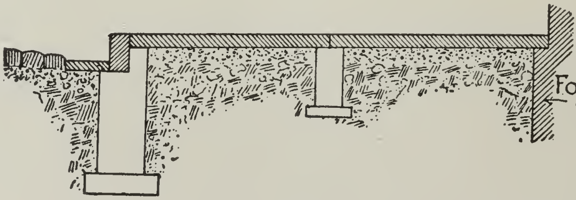

Fig. 82. Section Through Stone Sidewalk and Supports.

and also the way in which the curb and gutter is supported. The curbstone should be at least 4 inches thick, and on business streets 6 inches.

The dwarf wall should be about 14 or 16 inches thick and carried below the frost line.

If the sidewalk is laid in two courses a light wall of brick or stone should also be built under the middle to support the butting ends of the stones.

136. CEMENT WALKS.—Cement walks are extensively laid in the Western States, even in localities where excellent flagging stone is abundant and cement rather dear.

They are preferred on account of their smooth and even surface. When properly laid they are also very durable. They should be laid, however, where there is no danger of the grade being altered, and only after the ground has become thoroughly settled and consolidated.

Their durability depends principally upon the thickness of the concrete and the quality of the cement.

Only the best Portland cement should be used for the finishing, although natural cements are sometimes used for the concrete. Portland cement throughout, however, is to be preferred.

For first-class work cement walks should be laid as follows:

The ground should be leveled off about 10 inches below the finished grade of the walk and well settled by tamping or rolling. On top of this a foundation 5 inches thick should be laid of coarse gravel, stone chips, sand or ashes, well tamped or rolled with a heavy roller. The concrete should then be prepared by thoroughly mixing 1 part of cement to 1 part of sand and 3 of gravel, in the dry state, and then by adding sufficient water from a sprinkler to make a dry mortar. The concrete should be spread in a layer from 3 to 4 inches thick, commencing at one end, and should be thoroughly tamped. Before the concrete has commenced to set, the top or finishing coat should be applied, and only as much concrete should be laid at a time as can be covered the same day. If the concrete gets dry on top the finishing coat will not adhere to it. The top coat should be prepared by mixing 1 part of high grade Portland cement with 1 part of fine sand, or 1 part of clean, sharp, crushed granite, the latter being the best. The materials should be thoroughly dry-mixed, and enough water added to give the consistency of plastic mortar. The coat should be applied with a trowel to a thickness

of 1 inch and carefully smoothed and levelled on top between straight-edges laid as guides. Used in the above proportion, one barrel of Portland cement will cover about 40 square feet of concrete. After the walk is finished it should be covered with straw to prevent it from drying too quickly.

For brick paving see Article 331 and "Specifications for Brickwork" in Chapter XIII.

137. CURBING FOR SIDEWALKS.—Granite or concrete curbs may be used in conjunction with cement sidewalks. Where granite curbs are used they are either 6 inches or 8 inches in thickness, and from 24 inches to 36 inches in depth. The top surface and exposed gutter edge are hammer-dressed. It is the best modern practice, however, to provide cement-finished curbs in conjunction with well-constructed cement pavements. These curbs do not as a rule cost any more than granite curbs, and can be protected on the edge with a metal strip.

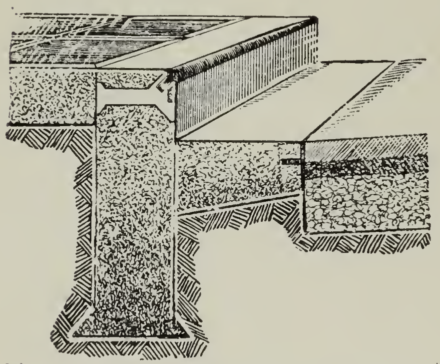
Fig. 83. Concrete Sidewalk Curb, with Steel Corner-Bar.

In the illustration, Fig. 83, is shown a concrete curb, the edge being armored with what is known as the "Wainwright galvanized-steel corner-bar." It is made with the section shown in the figure, and is tied into the concrete work at intervals with anchors or frogs. A curb of this kind finished, in place, costs from sixty cents to one dollar per lineal foot. Sometimes concrete curbs are reinforced along the edges with rolled steel channels, the web of the channel being vertical. The channels are anchored to the concrete work at intervals with wrought-iron pronged anchors.

11. SHORING, NEEDLING, UNDERPINNING AND BRACING

138. GENERAL CONSIDERATIONS.—The direction of these operations is generally left to the contractor, as the responsibility for the successful carrying out of the work devolves upon him.

The architect will be wise, however, when such operations are be-

ing carried on in connection with work let from his office, to see that proper precautions are taken for safety, and that all beams or posts have ample strength for the loads they have to support. When heavy or difficult work has to be done, it should, if possible, be intrusted to some careful person who has had experience in that class of work, as it is a trade by itself.

139. SHORING.—This means the supporting of a wall of a building by inclined posts or struts, generally from the outside, while its foundations are being carried down, or while its lower portions are being removed and girders and posts substituted.

The usual method of shoring the walls of buildings not exceeding three stories in height, especially when the shoring is done for the purpose of holding up the walls while being underpinned, is shown in Fig. 84.

The props or shores are inserted in sockets cut in the wall, with their lower ends resting on timber cribs supported on the ground. At least two sets of shores should be used, one to support the wall as low down as possible and the other to support it as high up as possible. The latter shores should not have a spread at the bottom of more

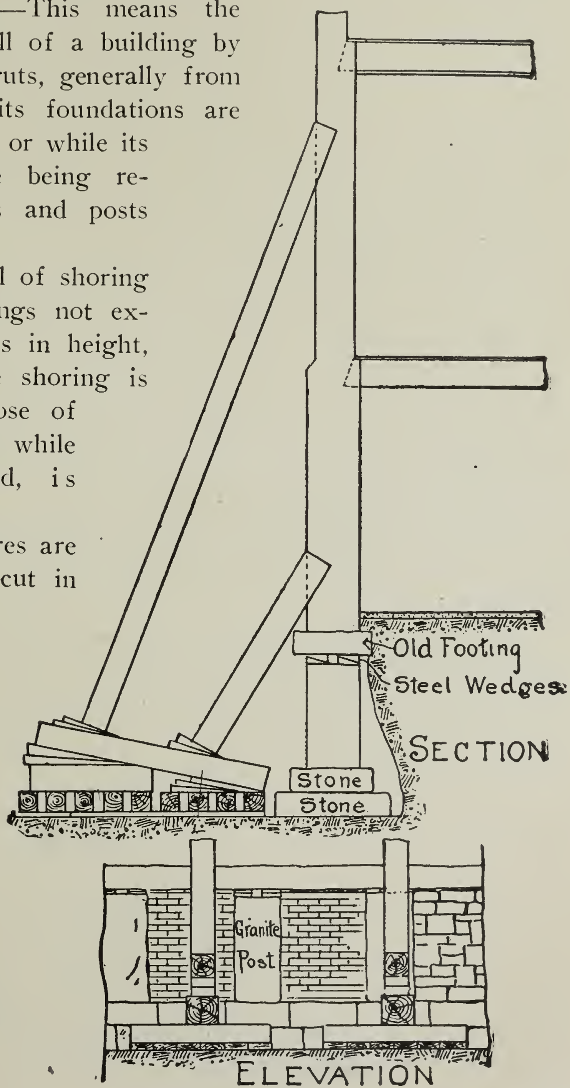

Fig. 84. Shoring or Inclined Bracing and Underpinning.

than one-third of their height. The platforms should be made sufficiently large, so as not to bring too great a pressure on the ground; and the shores should be driven into place by oak or steel wedges.

The shores should be spaced according to the height and thickness of the wall, and all piers and chimneys should be shored. Generally a spacing of 6 feet between the shores will answer.

Only a part of the foundation should be removed at a time, and as soon as three sets of shores are in place the wall should be underpinned, as described in Article 141. As fast as the wall is underpinned the first set of shores should be moved along, always keeping two sets in place, and working under or with one set.

Shoring may often be successfully employed for holding up the corner of a building while a pier or column is being changed; and sometimes when the lower part of the wall is to be removed and a girder slipped under the upper portion. In the latter case, however, needling is generally more successful and attended with less risk.

140. NEEDLING.—This term is given to the operation of supporting a wall, already built, on transverse beams or "needles" placed in holes cut through it and supported at each end by posts, jackscrews or grillage. At least one end of each horizontal beam should be supported by a jackscrew.

Wherever a long stretch of wall is to be built up at one time, and there is working space on each side of it, needling should be employed.

The beams must be spaced so near together that the wall will not crack between them, and the size of the beams must be carefully proportioned to the weight of the wall, floors, etc.

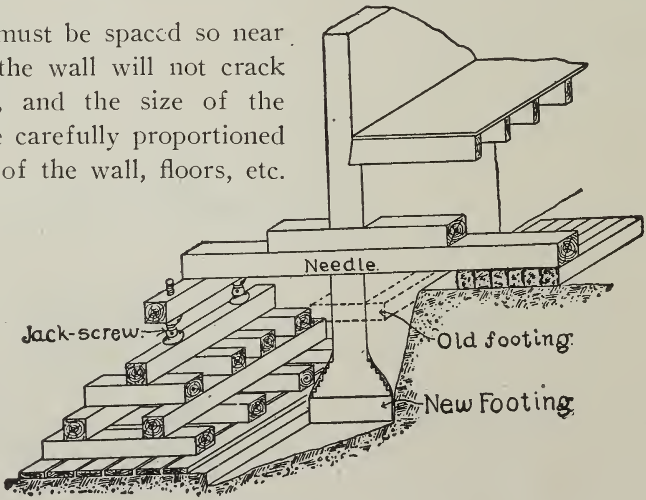

Fig. 85. Needling.

In very heavy buildings steel beams should be used for the needles, and they should be spaced not more than 2 feet apart. In three- or four-story buildings the needles may be of large timbers spaced from 4 to 6 feet apart. Each chimney or pier should have one or more needles directly under it.

When the first story walls or supports are to be removed, the beams or needles are usually supported on long timbers having screws under the ends; or, if the wall is very high or thick, a grillage of timber is built up and the jackscrews are placed on top of the grillage, the ends of the needles resting on a short beam supported by two screws, in the manner shown in Fig. 85.

When it is desired to remove the first story wall of a building for the purpose of substituting posts and girders, or for rebuilding the wall, holes should be cut in the wall from 4 to 6 feet apart, according to the weight to be supported and the quality of the brickwork or stonework, and at such a height that when the needles are in place they will come a few inches above the tops of the intended girders. Solid supports should then be provided for the uprights, the needles put through the wall, and posts, having screws in the lower ends, set under them, the bases of the screws resting on the solid supports previously provided. If the needles do not have an even bearing under the wall, iron or oak wedges should be driven in until all parts of the wall bear evenly on the needles. The jacks should then be screwed up until the wall is entirely supported by the needles, care being taken, however, not to raise the wall after the weight is on the needles.

The wall below may then be removed, the girders and posts put in place, and the space between the girders and the bottom of the wall built up with brickwork, the last course of brick or stone being made to fit tightly under the old work. The needles may then be withdrawn and the holes filled up.

141. UNDERPINNING.—Underpinning means carrying down the foundations of an existing building, or, in other words, putting new foundations under the old ones.

New footings may generally be put under a one or two-story building resting on firm soil without shoring or supporting the walls above, the common practice being to excavate spaces of only from 2 to 4 feet long under the wall, one at a time, sliding in the new footings and wedging up with stone, slate, or steel wedges.

Where the underpinning is to be 3 feet or more high, or where

the building is several stories in height, the walls should be braced or supported by shores or needles.

The usual method of underpinning the walls of buildings where a cellar is to be excavated on the adjoining lot is shown in Fig. 84.

Pits should first be dug to the depth of the new footings, and timber platforms built as shown; the shores should then be put in place and wedged up with oak wedges.

Sections about 3 feet wide between the shores should then be excavated under the wall, new footing stones laid, and the space between the new and old footings filled with brickwork or stonework. Where the height between the new and old footings does not exceed 5 feet, granite posts, if available, offer special advantages for underpinning. They should be from 12 to 18 inches wide on the face and of a thickness equal to that of the wall; they should be cut so as just to fit between the new and old work, and with top and bottom surfaces dressed square; and they should be set in a full bed of Portland cement mortar, with the top joints also filled with mortar and brought to a bearing with steel wedges.

If granite posts are not available, good flat stones, or hard bricks laid in cement mortar may be used instead, and wedged up under the old wall with pieces of slate or steel wedges driven into the upper beds of cement. Under heavy walls the latter wedges only should be used. If the bottom of the old footings is of soft brickwork, pieces of hard flagging, with full beds of cement mortar, may be placed under them, and the wedges driven under the flagging so as to bring the latter "hard up" under the old work. The portions of wall between these sections should then be underpinned in the same way and the shores moved along.

Where granite posts are used they may be placed 3 feet apart and the space between built up with flat rubble or hard bricks, wedged up under the old wall with slate.

If the soil under the old building is sufficiently firm, so that it will not cave or "run away," and if there is working space beneath the lower floor, the ground may be levelled off, platforms of planks and timbers placed on top of it, and needles used for supporting the wall, as shown in Fig. 85. Where needles are used, all of the underpinning under the portion of wall supported may be put in at the same time.

The underpinning should be done as quickly as possible after the shores or needles are in place, so as not to require their support for

a longer time than necessary. The needles or shores should, however, not be removed until the cement has had time to set.

142. NEW FOUNDATIONS UNDER OLD ONES.—In building modern tall office buildings foundations generally have to go below those of adjacent buildings, and, the ground being compressible, new party-wall foundations are almost invariably required. The consequence is that old walls have to be supported while new foundations are being put under them. This is usually done by means of steel needles placed from 12 to 24 inches apart, their ends resting on long beams placed parallel with the wall and supported by jackscrews. Very often an entire wall is supported in this way, several hundred jackscrews being required for the purpose.

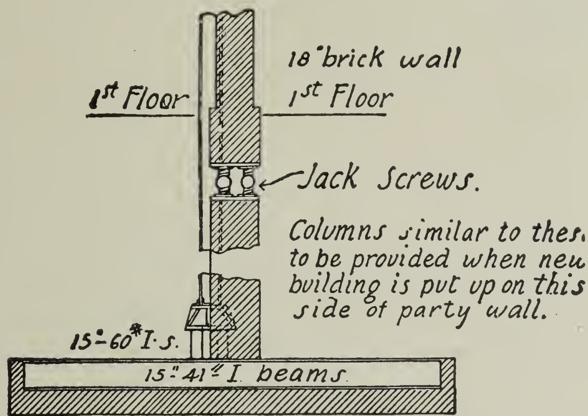

Fig. 86. Wall and Footing, New York Life Insurance Company's Building, Chicago.

In erecting buildings of skeleton construction it is often impracticable to remove old walls, and new buildings are supported by iron columns placed against walls and resting on new foundations put in under the old ones. In building the New York Life building in Chicago such was the case, and the adjacent wall, as shown in Fig. 86, was held up by jackscrews, which were inserted to keep the wall in place during the settlement of the new work. As the new foundations settled the jacks were screwed up, so as to keep the old walls in their original position. In this case the jacks were left in place.

143. EXAMPLE OF HEAVY NEEDLING AND UNDERPINNING.—An interesting example of foundation construction embodying the use of needle-beams in underpinning, is found in

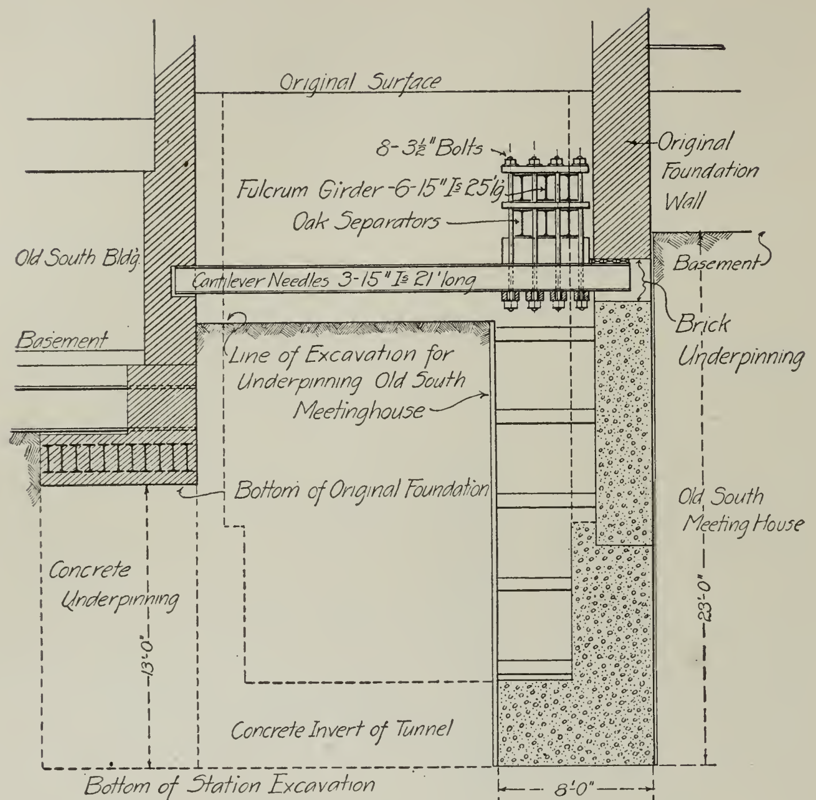

Fig. 87. Heavy Needling and Underpinning, Old South Meeting House and Old South Building, Boston.

connection with the construction of the subway tunnel in Boston. The Washington Street tunnel of the Boston Transit Commission Subway is parallel with and close to the front walls of the Old South Meeting-House and Old South building. It extended considerably below the foundations of both of these buildings, and it was necessary to provide an entrance to the Subway between their walls.

Fig. 87 shows the ingenious construction employed in the operation. To the left of the figure is the Old South building, which is an 11-story and basement office-building, of modern steel construction; to the right of the figure is shown the heavy masonry wall and original foundation of the Old South Meeting House. In proceeding with the operation the earth was excavated between the buildings from the original surface to a depth of 9 feet. It was

necessary to underpin about 80 feet of the wall of the Meeting-House, and this was done by cutting holes in the walls at intervals of 15 feet, and inserting needle-beams consisting of three 15-inch I-beams, which projected into the wall of the Old South building, and were supported by the fulcrum girder about 25 feet long, consisting of six 15-inch I-beams supported on cribbing at each end. The needle-beams were hung from this girder by eight 3½-inch suspension-bolts, which were drawn up tight until the fulcrum girder had a deflection of about ½ an inch. The weight of the Old South building provided the reaction on the long ends of the needles, which acted as double cantilevers. When the wall was thus supported, the new concrete foundation wall was put in place, resting upon the concrete invert of the tunnel, and the old wall of the Meeting-House was underpinned with brick between the top of the concrete and the bottom of the wall. Each pier of the Old South building was underpinned separately, and was supported on a needle formed of six 15-inch I-beams set close together under the pier, and suspended from a cantilever fulcrum girder, made with nine 15-inch I-beams. In the same way, the Meeting-House wall was utilized to provide the necessary reaction at the short ends of the cantilevers.

After the weight of the pier of the Old South building had been transferred to the needles, a trench 8 feet long, parallel to the building, was excavated under the wall and the fulcrum girders to a depth of 35 feet below the street level, and a concrete footing 13 feet in height was built in. This footing, or pier, was capped with brickwork, and the old foundation wall brought to a bearing with cast-iron plates and iron wedges driven in. After all of the concrete piers were in place the space between was excavated and concrete walls built between.

144. BRACING.—Where buildings have been built with a party-wall, and one of the buildings is torn down, leaving the adjacent walls unsupported, they should be protected from falling by either spreading braces or inclined shores, according to special conditions.

Where there is a building on the opposite side of the vacant lot, and less than 40 or 50 feet away, the walls of both buildings may be best supported by spreading braces, in the manner shown in Fig 88.

If the distance between the buildings does not exceed 25 feet, the

braces may be arranged as shown at *A* or *B*. If it exceeds 25 feet, the braces must be trussed in a manner similar to that shown at *C*.

Iron or steel rods are preferable for the vertical ties, as they can be screwed up, and any sagging caused by shrinkage in the joints can be overcome.

If the buildings are very high every other story should be braced. The ends of the braces or trusses must be supported vertically, so that they will not slip down. When there are offsets in the wall they serve as vertical supports; when there are no offsets, the braces should be supported by vertical posts, starting from the foundations, or sockets should be cut in the wall with corbels let in and bolted through from the inside.

A truss should be placed in line with the fronts, and should be proportioned so as to resist the thrust from any arches there may be there. The braces should be about 8 by 8 or 10 by 10 inches in section, with 6 by 12 uprights against the wall, the ends of the braces being mortised into the uprights.

If there is no wall opposite the building to be braced, inclined braces must be used, arranged like the shores shown in Fig. 84, only with a greater inclination. The ends of the braces should be brought to a bearing by oak wedges.

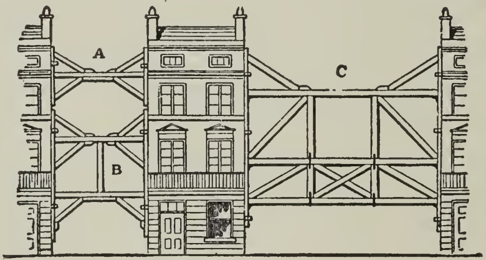

Fig. 88. Spreading-Braces or Trusses.

CHAPTER IV.

Limes, Cements and Mortars.

I. COMMON LIMES.

145. IMPORTANCE OF THE SUBJECT.—There is hardly any material used by the architect or builder upon which so much depends as upon mortar in its different forms, and it is important that the architect should be sufficiently familiar with the different kinds of limes and cements to know their properties, and to understand their adaptation to and suitability for different kinds of work. He should also be able to judge of the qualities of the materials with sufficient accuracy to prevent any which are actually worthless from being used, and he should have some knowledge of mortar mixing.

146. COMMON LIME.—Common lime, sometimes called quicklime or caustic lime, has a specific gravity of from 2.3 to 3.15, is amorphous, somewhat spongy, highly caustic, quite infusible, possesses great affinity for water, and if brought into contact with it will readily combine with about 30 per cent of its weight, passing into the condition of slaked or hydrated lime ($Ca\,H_2\,O_2$). It is produced by the calcination at moderate heat of limestones of varying composition. This is done by burning the stone in kilns of types varying according to the localities in which they are employed. For example, in the kilns of one type, the "continuous, vertical, mixed-feed" kilns, the broken stone and fuel (generally coal) are put in in layers, the fire lighted at the bottom, and as the lime drops to the bottom new layers of stone and coal are put in at the top, so that the kiln may be kept burning for weeks at a time. The carbonic acid gas and any moisture in the stone are driven off and allowed to escape. The limestones from which limes and cements are produced differ greatly in their composition, ranging from practically pure carbonate of lime, such as oolitic and coquina limestone, white chalk and marble, to stones containing 10 per cent or more of impurities, such as silica, alumina (clay), magnesia (magnesium oxide), iron, and traces of the alkalies, soda and potash. The quality of the lime will consequently depend much upon the percentage of impurities contained in the stone from which it is made. Strictly speaking, magnesia should not be classed as an "impurity," as it simply serves to replace an equivalent

amount of calcium carbonate. Lime is manufactured in nearly every State in the Union, each locality generally producing its own supply. The only political divisions producing exceedingly small quantities of lime or no lime at all are Delaware, Louisiana, Mississippi, New Hampshire, North Dakota and the District of Columbia.

There is considerable difference, however, in the limes of different localities, and before using a new lime the architect should make careful inquiries regarding its quality, and if it has not been much used it would be better to procure a lime of known quality, at least for plastering purposes; for common mortar it is not necessary to be so particular.

For commercial purposes limes have been classified as follows:

"Group A.—High-calcium limes: Limes containing less than 5 per cent of magnesia. The limes of this group differ among themselves according to the amount of silica, alumina, iron, etc., contained. A lime carrying less than 5 per cent of such impurities is a 'fat,' or 'rich' lime, as distinguished from the more impure 'lean' or 'poor' limes."

"Group B.—Magnesian limes: Limes containing over 5 per cent (*usually* 30 per cent or over) of magnesia. These limes are all slower slaking and cooler than the high-calcium limes of the preceding group, and they appear to make a stronger mortar. They are, however, less plastic or 'smooth,' and in consequence are disliked by workmen. As commercially produced, they usually carry over 30 per cent of magnesia."

The chemistry of lime-burning, reduced to its simplest terms, may be expressed as follows:

1.—For a limestone, absolutely pure,

Limestone (Ca CO_3 + heat = Ca O (high-calcium lime) + CO_2 (carbon dioxide).

2.—For limestone containing magnesium carbonate, though otherwise pure:

Limestone (Ca CO_3, Mg CO_3) + heat = Ca O, Mg O (magnesian lime) + CO_2 (carbon dioxide).

As an example of commercial quantitative values, 100 lbs. of pure limestone will give 56 lbs. of quicklime (Ca O) and 44 lbs. of carbon dioxide (CO_2); and 100 lbs. of limestone consisting of 60 per cent lime carbonate and 40 per cent magnesium carbonate, will give

about 34 lbs. of lime (Ca O), 19 lbs. of magnesia (Mg O) and 47 lbs. of carbon dioxide (CO_2).

In the Eastern cities lime is sold by the barrel, weighing for Rockland, Me., lime 220 lbs. net; but in many parts of the country it is sold in bulk, either by the bushel or by weight. When shipped in bulk it is generally sold by the bushel of 80 lbs., 2½ bushels or 200 lbs. of lime being considered as equivalent to a barrel. Other weights are 230 lbs. net per barrel, 75 lbs. per bushel, and 64 lbs. per cubic foot.

The following are average quantitative equivalents for one barrel of lime: 2¾ barrels of paste, mortar sufficient for laying 3 perch of rubble stone or 1,000 to 1,200 bricks, plaster for 28 yards of 3-coat work or for 40 yards of 2-coat work.

Lime will keep for a long time in bulk when the climate is very dry, but it soon slakes in damp climates, for example, along the sea coasts, unless enclosed in barrels.

147. CHARACTERISTICS OF GOOD LIME.—Good lime should possess the following characteristics: 1. Freedom from cinders and clinkers, with not more than 10 per cent of other impurities. 2. It should be in hard lumps, with but little dust. 3. It should slake readily in water, forming a very fine, smooth paste, without any residue. 4. It should dissolve in soft water.

There are some limes which leave a residue consisting of small stones and silica and alumina in the mortar box, after the lime is drained off. Such limes may answer for making mortar for building masonry, but should not be used for plastering if a better quality of lime can be procured.

148. SLAKING AND MAKING INTO MORTAR.—The first step in the manufacture of lime mortar consists in the *slaking* of the lime. During the operation of lime-slaking the chemical combination that takes place may be expressed by the formula: Lime (CaO) + water (H_2O) = lime hydrate (CaO_2H_2). Lime hydrate is a fine white powder, with specific gravity of 2.078. When quicklime is slaked at the building operation, the ordinary practice is to do the slaking either by putting the lime in a water-tight box and adding water through a hose or by pails, or by forming on a plank floor or on a bed of sand, a circular wall of sand, shovelling into the ring thus formed the lime, and turning on the water from a hose. When the process of slaking is completed the slaked lime is covered with a layer of sand until wanted. Different limes require different

volumes of water for slaking. The water is rapidly absorbed by the lime, causing a great elevation of temperature, the evolution of hot and slightly caustic vapor, and the bursting of the lime into pieces; and finally the lime is reduced to a powder, the volume which is from two to three and a half times the volume of the original lime. In this condition the lime is said to be slaked and is ready for making into mortar. The best limes slake without leaving a residue. The mortar is made by mixing clean, sharp sand with the slaked lime in the proportion of 1 part of lime to from 2 to 5 of sand by volume. The New York Building Code requires that not more than 4 parts of sand to 1 part of lime shall be used. Practically the proportion of sand is seldom, if ever, measured, but the sand is added till the person mixing the mortar thinks it is of the proper proportion. For brickwork over a certain proportion of sand cannot well be added, for if there is too much sand in the mortar it will stick to the trowel and will not work easily. With stonework the temptation is always to add too much sand, as sand is generally *cheaper* than lime. The architect or superintendent should take pains to make himself familiar with the appearance of good mortar, so that he can readily tell at a glance if it has too much sand. Mortar that contains a large proportion of lime is said to be *rich*; if it has a large proportion of sand and works hard it is said to be *stiff*, and to make it work more readily it is *tempered* by the addition of water. Tempered mortar looks much richer than stiff mortar, though it may not be so. If the mortar slides readily from the trowel it is of good quality, but if the mortar sticks to the trowel there is too much sand in proportion to the lime. The color of the mortar depends much upon the kind and color of the sand used.

Some limes when slaked leave a residue of stones, lumps and gravel, so that instead of mixing the mortar in the same box in which the lime is slaked, a larger proportion of water is added, and the slaked lime and water (about as thick as cream) is run off through a fine sieve into another box, in which the mortar is mixed. Such lime does not make as good mortar as that which leaves no impurities, but it is sometimes used in ordinary brickwork and stonework.

The general custom in making lime mortar has been to mix the sand with the lime as soon as the latter is slaked and to let it stand until required for use. Much stronger and better mortar will be obtained, however, if the sand is not mixed with the slaked lime until the mortar is needed.

148a. HYDRATED LIME.—When quicklime is slaked on the work, it is usually done by careless laborers in a very indifferent manner, and the slaked lime seldom reaches a condition of theoretical efficiency. In order to overcome this difficulty, ready-slaked lime, carefully prepared at the lime-plants, has been introduced during recent years. This is placed on the market under the names of "new-process lime," "hydrated lime," "limoid," etc. Its manufacture involves the grinding of the lump quicklime to a fairly uniform, small size; the thorough mixing of the resulting grains of powder with the proper proportion of water; and the reduction of the slaked lime to a uniform fine powder by passing it through a sieve or by using other methods.

The product is generally sold in either heavy, closely woven burlap or duck bags, containing 100 pounds, 20 bags to the ton, or in paper bags containing 40 pounds, 50 bags to the ton. It gains in weight during the process of manufacture, one ton of quicklime (2000 pounds) giving from 2400 to 2600 pounds of hydrated lime.

148b. HYDRATED LIME AND PORTLAND CEMENT MIXED.—Very interesting tests have been made on the strength of a mixture of hydrated lime and Portland cement, and the results show some very interesting data. Up to certain limits the addition of hydrated lime to Portland cement mortar makes the latter easier to work and more plastic; but the most interesting result noticed is an actual increase in tensile strength when the addition does not exceed 10 or 20 per cent.

149. SAND.—The reason sand is used in mortar is because it prevents excessive shrinkage and reduces the cost of the lime or the cement; and while its addition to cement mortar always weakens it, its addition to lime mortar in the proportion of 1 to 2, for example, adds to the latter's strength.

Sand is obtained from river beds, from the seashore and from banks or pits. Pit or bank sand, clean, is generally considered the best for mortar. Excellent sand, however, is often obtained from river beds. The objection to sea sand is the alkaline salt it contains, which attracts and retains moisture and causes dampness in walls. The usual specifications for sand used in making mortar require that it shall be angular in form, of various sizes, and absolutely free from all dust, loam, clay, earthy or vegetable matter, and also from large stones.

Recent tests and experiments, however, seem to lead engineers to

the following conclusions: (1) It is not necessary to have the grains sharp; (2) the coarseness of the grains governs largely the quality; (3) in mortars loam or clay is sometimes injurious, and sometimes beneficial, at least in cement mortars; (4) the pouring of water into sand does not accurately determine the voids, which can be found by weighing the sand and finding its moisture; (5) because of the effect of varying degrees of moisture, a study of voids does not result in a method of comparing sands; (6) dry sand measured loose is heavier than moist sand; (7) when mixed with cement coarse sand makes a denser mortar and requires less water than fine sand; (8) fine sand with grains of uniform size, and screened coarse sand when dry, have nearly the same weight, but with ordinary moisture fine sand is lighter and more porous than coarse sand; (9) the weight of mixed sand is usually greater and the volume of voids smaller than that of coarse or fine sand.

It is generally necessary to pass the sand through a screen to secure the proper degree of fineness. For rough stonework a combination of coarse and fine sand makes the strongest mortar. For pressed brickwork it is necessary to use very fine sand. The architect or superintendent should carefully inspect the sand furnished for the mortar, and if he wishes to test its cleanliness, a handful put in a tumbler of water will at once settle the question, as the dirt will separate and rise to the top. Another simple method of testing sand is to squeeze some of the moist sand in the hand, and, if upon opening the hand the sand is found to retain its shape, it must contain dirt or loam or clay, but if it falls down loosely it may be considered as clean. Sand containing loam or clay is usually rejected and ordered from the premises, and it is safe for the architect to work on the principle that loam or clay, if in sufficient quantity to be detected by the touch, or appearance, or by leaving a stain when rubbed between damp hands, is harmful, and tends to weaken the cementing material in the case of most lime mortars, whatever may be the effect of small percentages in the case of certain cement mortars. As a rule, it is better that the sand should be too coarse than too fine, as the coarse sand takes more lime and makes the stronger mortar. Some masons attempt the use of fine sandy loam in their mortar, as it takes the place of lime in making the mortar work easily; but it generally tends to weaken the mortar, and it is better not to permit its use.

The specific gravity of dry sand may be taken at 2.65.

150. WHITE AND COLORED MORTARS.—White and col-

ored mortars to be used in laying face bricks should be made from *lime paste* or *putty* and finely screened sand. After the slaked lime has stood for several days the water evaporates and the lime thickens into a heavy paste, much like putty, from which it takes its name of "lime putty." By the time the putty is formed the lime should be well slaked and have no tendency to swell or "pop." Colored mortar is made by the addition of mineral colors to the white mortars. Colored mortar should *never* be made with *freshly slaked lime,* but only with lime putty at least three days old. For Mortar Colors see Articles 216 to 219.

Clear lime putty may be kept for a long time in casks, for use in making colored mortar, only a little mortar being made up at a time. Common lime when slaked and evaporated to a paste may be kept for an indefinite time in that condition without deterioration, if protected from contact with the air so that it will not dry up. It is customary to keep the lime paste in casks or in the boxes in which it was slaked, covered over with sand, to be subsequently mixed with it in making the mortar.

151. SETTING OF LIME MORTAR.—Lime mortar does not set like cement mortar, but gradually absorbs carbonic acid from the air and becomes in time very hard; the process, however, requires from six months to several years, according to the thickness of the mortar and its exposure to the atmosphere. If permitted to *dry* too quickly it never attains its proper strength. If frozen, the process of setting is delayed and the mortar is much injured thereby. Alternate freezing and thawing will entirely destroy the strength of the mortar. Lime mortar will not harden under water, nor in continuously damp places, nor when excluded from contact with the air.

In regard to all the phenomena of the process of the setting of lime mortar in their minutest details, there does not seem to be as yet a complete unanimity of opinion on the part of those who have made the subject one of special study. There is a general agreement that the chemical changes take place for the most part at the outer and exposed portion of the lime-mortar joints, and that the mortar in the interior of a wall never acquires what might be called "complete hardness," or at least not until after the lapse of long periods of time.

Some investigators, for example, emphasize the fact of the probable chemical action that takes place between the sand and the lime, and the resulting formation of lime silicates; while others claim that

the effect of this is very slight and of little engineering importance.

One authority, Mr. Edwin C. Eckel,* states that "the hardening of lime mortars is a simple process. It may be accepted as proven that lime mortars harden by simple recarbonation, the lime gradually absorbing carbon dioxide from the atmosphere, and becoming, in fact, artificial limestone. As this absorption can take place only on the surface of the masonry, the lime mortar in the interior of a wall never becomes properly hardened. In this process the sand of the mortar takes no active part. It is merely an inert material, added solely in order to prevent shrinkage and consequent cracking."

Professor Clifford Richardson, one of the highest authorities on questions of this kind, says:

"The setting of lime mortar is the result of three distinct processes which, however, may all go on more or less simultaneously. First, it dries out and becomes firm. Second, during this operation, the calcic hydrate, which is in solution in the water of which the mortar is made, crystallizes and binds the mass together. Hydrate of lime is soluble in 831 parts of water at 78° Fahr.; in 759 parts at 32° and in 1136 parts at 140°. Third, as the per cent of water in the mortar is reduced and reaches five per cent, carbonic acid begins to be absorbed from the atmosphere. If the mortar contains more than five per cent this absorption does not go on. While the mortar contains as much as 0.7 per cent the absorption continues. The resulting carbonate probably unites with the hydrate of lime to form a subcarbonate, which causes the mortar to attain a harder set, and this may finally be converted to a carbonate. The mere drying out of mortar, our tests have shown, is sufficient to enable it to resist the pressure of masonry, while the further hardening furnishes the necessary bond."

Mr. C. F. Mitchell† gives a simple statement of the chemistry of lime mortar setting, as follows:

"The setting of lime depends on the absorption of CO_2 from the atmosphere by the particles of slaked lime in solution in the mortar, the carbon dioxide being soluble in water. The CaO and CO_2 combine to form crystals of $CaCO_3$, these being deposited, and giving up the H_2O, which combines with the next particle, forming it into a saturated solution, rendering it into the necessary condition to take up another molecule of CO_2; this in its turn crystallizes and

* "Cements, Limes and Plasters." Edwin C. Eckel.

† "Building Construction." Charles F. Mitchell.

is deposited; this process is repeated till the whole has set. The crystals always have a tendency to adhere to something rough and hard, such as sandy particles or the surfaces of bricks; for this reason the addition of sand up to a certain ratio increases the strength of the mixture, the best ratio being one part pure lime to one of sand, the maximum being one of pure lime to three parts of sand.

"A long time elapses before pure limes harden, owing to their depending upon external aid to attain this state. If lime alone were used the surface would set and form an impervious layer, and so check the CO_2 from acting on those particles below the surface, the moisture in which evaporates and leaves the same in the state of a powder; and even when a large proportion of sand is used and the mass made porous, the supply of CO_2 must necessarily be small, and a long time elapses before the material hardens. Pure lime mortar built in thick walls never hardens nor sets, but crumbles into a friable powder.

"For this reason pure limes should be avoided for constructional work, and a lime or cement which does not depend on external aid to set be used."

152. PRESERVING LIME.—Fresh burned lime will readily absorb moisture from a damp atmosphere, and will in time become slaked, thereby losing all of its valuable qualities for making mortar. It is therefore important that great care should be taken to secure freshly burned lime and to protect it from dampness until it can be used. If the lime is purchased in casks it should be kept in a dry shed or protected by canvas, and if it is bought in bulk it should be kept in a water-tight box built for the purpose.

On no account should the superintendent permit the use of air-slaked lime, as it is impossible to make good mortar with it.

153. DURABILITY OF LIME MORTAR.—Good lime mortar, when protected from moisture, has been considered by many architects to have sufficient strength for ordinary brickwork above ground, except when heavily loaded, as in piers. It continues to grow harder and stronger for many years after it is in place. The writer knows of old walls in which the lime mortar was as strong as the bricks, and where the adhesion of the mortar to the bricks was greater than the cohesion of the particles of the bricks.

A specimen of mortar, supposed to be the most ancient in existence, obtained from a buried temple on the island of Cyprus, was

found to be hard and firm, and upon analysis appeared to be made of a mixture of burnt lime, sharp sand and gravel, some of the fragments being about ½ an inch in diameter. The lime was almost completely carbonized.*

Lime mortar, however, attains its strength slowly, and where high buildings are built rapidly the mortar in the lower story does not have time to get sufficiently hard to sustain the weight of the upper stories, and for such work cement should be added to the lime mortar.

Some cities limit the use of lime mortar to the brickwork of chimneys in frame buildings, but the building laws of many cities allow its use in all but fire-proof buildings. The allowable stress, however, is limited, for example, in the case of brick piers in one case, to seven tons per square foot.

For the brickwork of ordinary buildings, and for light rubble foundations, lime and natural cement mortar forms a suitable and frequently used mixture; and when a still superior quality and strength are wanted, lime and Portland cement mortar is used. Beyond these come the natural and Portland cement mortars without the lime.

2. HYDRAULIC LIMES.

154. GENERAL DESCRIPTION.—Hydraulic limes are those containing, after burning, enough lime to develop, more or less, the slaking action, together with sufficient of such foreign constituents as combine chemically with lime and water, to confer an appreciable power of *setting* under water, and without access of air.

The process of *setting* is entirely different from that of drying, which is produced simply by the evaporation of the water. Setting is a chemical action which takes place between the water, lime and other constituents, causing the paste to harden even when under water.

Hydraulic lime or cement should not be used after it has commenced to set, as the setting will not take place a second time and the strength of the mortar will be lost.

In the hydraulic limes used for making mortar, the constituent which confers hydraulicity is *clay,* or more correctly, the silica contained in the clay.

Mr. Edwin C. Eckel states† that "theoretically the proper composition for a hydraulic limestone should be calcium carbonate 86.8

*William Wallace, Ph.D., F. R. S. E., in London *Chemical News,* No. 281.
† "Cements, Limes and Plasters." Edwin C. Eckel.

per cent and silica 13.2 per cent. The hydraulic limestones in actual use, however, usually carry a much higher silica percentage, reaching at times to 25 per cent, while alumina and iron are commonly present in quantities which may be as high as 6 per cent. The lime content of the limestones commonly used varies from 55 per cent to 65 per cent."

The same authority gives* another definition of hydraulic limes as follows: "The hydraulic limes include all those cementing materials (made by burning siliceous or argillaceous limestones) whose clinker after calcination contains so large a percentage of lime silicate (with or without aluminates and ferrites) as to give hydraulic properties to the product, but which at the same time contains normally so much free lime (CaO) that the mass of clinker will slake on the addition of water."

Commercial as well as theoretical differences make it convenient to divide the true hydraulic limes into two groups, the classification depending upon the extent to which the so-called impurities of the limestone are present, reduce the slaking action, and confer upon the lime the property of setting under water. These groups are

1. Eminently hydraulic limes.
2. Feebly hydraulic limes.

During the calcination of the eminently hydraulic limes a by-product is produced. This is usually put on the market separately, and is known as "grappier cement."

By treating the feebly hydraulic limes with sulphuretic acid according to the formulas of a special process developing new properties, a secondary product results, which also is marketed separately as "selenitic lime," or "Scott's cement." This cement cannot compete with the excellent natural cements of the United States.

The following is an analysis† of a typical hydraulic lime, after slaking:

Silica ($Si\ O_2$)	22.0
Alumina ($Al_2\ O_3$)	2.0
Iron Oxide ($Fe_2\ O_3$)	2.0
Lime ($Ca\ O$)	62.0
Magnesia ($Mg\ O$)	1.5
Sulphur trioxide ($S\ O_3$)	0.5
Carbon dioxide ($C\ O_2$)	0.0
Water	10.0
	100.0

* *American Geologist*, March. 1902, p. 152.

† Le Chatelier, Trans. Am. Inst. Min. Engrs., vol. 22, p. 16.

Artificial hydraulic lime can be manufactured by mixing together, in proper proportions, soft chalk or thoroughly slaked common lime and unburnt clay, then burning and grinding in much the same manner as in the manufacture of Portland cement; but as the process of manufacture is nearly as expensive as for making Portland cement it is more profitable to make cement, on account of its superior hydraulic energy.

A very simple experiment will determine if a lime is hydraulic or not: Make a small cake of the lime paste, and after it has commenced to stiffen in the air, place it in a dish of water so that it will be entirely immersed. If it possesses hydraulic properties it will gradually harden, but if it is not hydraulic it will soften and dissolve.

Limestones with a composition suitable for making hydraulic lime are very common in England and on the Continent of Europe, the siliceous and argillaceous limestones of Teil, in France, being among the most noted. As hydraulic limes are usually only feebly hydraulic when compared with good natural cements or Portland cements, and as the United States is rich in materials suitable for the manufacture of natural cements, these hydraulic limes have never been manufactured in this country and they have never been known as an article of commerce, although the importations each year are considerable.

155. LAFARGE CEMENT.—Among the non-staining cements, the Lafarge Cement is the best known, and has been on the American market for many years. It is a grappier cement of very satisfactory composition, made at Teil, France, and belongs in the class of eminently hydraulic limes. These latter and the grappier cements have a relatively small percentage of iron and soluble salts, and besides being light colored, do not stain masonry, built, for example, of marble, limestone and other porous stones. They are unlike Portland and Rosendale cement in this respect, and hence are especially desirable in setting such stones.

This non-staining property is possessed also by some of the foreign Puzzolan cements.

For setting large stones, mix 1 part by volume of lime paste to 4 parts of the cement, to retard the setting of the cement until the stones are well bedded.

The following are the analyses of two typical Lafarge cements*:

	(1)	(2)
Silica ($Si O_2$)	31.10	27.38
Alumina ($Al_2 O_3$)	4.43	2.61
Iron Oxide ($Fe_2 O_3$)	2.15	1.02
Lime ($Ca O$)	58.38	58.38
Magnesia ($Mg O$)	1.09	0.46
Alkalies ($K_2 O$, $Na_2 O$)	0.94	n. d.
Sulphur trioxide ($S O_3$)	0.60	0.43
Carbon dioxide ($C O_2$)	1.28	n. d.
Water	n. d.	n. d.

156. NON-STAINING CEMENTS IN GENERAL.—The following is a typical specification for these cements: "Non-staining cement must be of a brand that has been in use for at least two years to test its non-staining qualities, have a specific gravity of not less than 2.75, contain not more than 2 per cent of sulphuric acid, nor more than 3 per cent of magnesia, be of such fineness that 85 per cent will pass through a No. 100 standard sieve, and in briquettes of neat cement, when tested as usually specified for Portland cement, have a tensile strength of 200 pounds per square inch. All cement must be of uniform quality, and when delivered must be in original packages with the brand and maker's name marked thereon, and must be kept dry."

3. NATURAL CEMENTS.

157. CLASSIFICATIONS OF CEMENTING MATERIALS.—Cementing materials in general may be classified as 1, Common Limes; 2, Hydraulic Limes; 3, Natural Cements; 4, Portland Cements; 5, Puzzolans or Slag Cements.

They also naturally fall into two groups; non-hydraulic cementing materials and hydraulic cements. To the first group belong Plaster of Paris, Keene's Cement, cement plaster, common lime, etc., and to the second group belong all but the first of the above mentioned five subdivisions. Having considered the common limes and the hydraulic limes, the natural cements will be considered in the next article.

A comparison of the compositions of the different cementing materials, excluding the plasters, will aid in making the basis of the classification clear, and the following is a table† giving some typical analyses:

* (1.) C. F. McKenna, analyst, 1897.
* (2.) *Engineering News*, vol. 47, p. 23., Jan. 9, 1902.
† "Concrete, Plain and Reinforced." Taylor and Thompson.

TABLE IX.

TYPICAL ANALYSES OF CEMENTS.

	Portl'nd Cement		Natural Cement							Common Lime	
			American		Eng	French					
	Lehigh Valley[1] (mixed rock)	Western[2] (marl and clay)	Eastern Rosendale[3]	Western Louisville[3]	Roman[4]	Vassey[5]	Grappiers[6]	Puzzolan Cement[7]	Hydraulic Lime (Le Tiel)[8]	Lime[9]	Magnesian Lime[10]
Silica (SiO_2)	21.31	21.93	18.38	20.42	25.48	22.60	26.5	28.95	21.70	1.03	1.12
Alumina (Al_2O_3)	6.89	5.98	15.20 (Alumina and Iron Oxide)	4.76	10.30	8.90	2.5	11.40	3.19	1.27 (Alumina and Iron Oxide)	0.68
Iron Oxide (Fe_2O_3)	2.53	2.35		3.40	7.44	5.30	1.5	0.54	0.66		.....
Calcium Oxide (CaO)	62.89	62.92	35.84	46.64	44.54	52.69	63.0	50.29	60.70	97.02	58.51
Magnesian Oxide (MgO)	2.64	1.10	14.02	12.00	2.92	1.15	1.0	2.96	0.85	.0.68	39.69
Sulphuric Acid (SO_3)	1.34	1 54	0.93	2.57	2.61	3.25	0.5	1.37	0.60	.....	.....
Loss on Ignition	1.39	2.91	3.73	6.75	3.68	6.11	5.0	3.39	12.20	.....	.....
Other Constituents	0.75	.....	11.46	3.74	1.46	.....	....	0.30	0.10	.....	.....

1. W. F. Hildebrand, Society of Chemical Industry, 1902, Vol. XXI.
2. W. F. Hildebrand, Journal American Chemical Society, 1903, 25, 1180.
3. Clifford Richardson, *Brickbuilder,* 1897, p. 229.
4. Stanger & Blount, Mineral Industry, Vol. V., p. 69.
5. Candlot, Ciments et Chaux Hydrauliques, 1898, p. 174.
6. Le Chatelier, Annales des Mines, September and October, 1893, p. 36.
7. Report of the Board of U. S. Army Engineers on Steel Portland Cement, 1900, p. 52.
8. Candlot, Ciments et Chaux Hydrauliques, 1898, p. 24.
9. Rockland-Rockport Lime Company.
10. Western Lime and Cement Company.

158. DEFINITION OF NATURAL CEMENT.—Natural cement is the product resulting from the burning and subsequent pulverization of a natural clayey limestone containing from 15 to 40 per cent of silica, alumina and iron oxide. There is no preliminary mixing and grinding. The temperature of the burning is about that of the ordinary lime-kiln, and not sufficient to cause vitrification. Almost all of the carbon dioxide is driven off, there is a combination of the lime with the silica, alumina and iron oxide, and the formation of a mass containing silicates, aluminates and ferrites of lime; or in case the original rock contains magnesium carbonate, the formation of magnesia and magnesian compounds. As this resulting mass, as it comes from the kiln, will not slake if water be poured on it, it is ground into a fine powder, which, when mixed with water, hardens or sets rapidly either in air or in water. The property of hydraulicity, as in the case of all silicate cements, is due principally to the formation of tricalsic silicate ($3CaO, SiO_2$).

159. EARLY USE OF NATURAL CEMENTS.—Cements in general have been used from the earliest known civilizations. The Egyptians, Carthagenians and Romans knew their properties and employed them in their works. Recent discoveries seem to point to a practical knowledge of their value possessed by the ancient peoples of Mexico and Peru. After an apparent general loss of the art of their manufacture during the Middle Ages and early modern times, it appears to have been rediscovered about the middle of the eighteenth century, on the occasion of the building of the Eddystone lighthouse, when John Smeaton, the engineer in charge, produced a good hydraulic lime or natural cement from argillaceous limestones. In England, again, just at the beginning of the nineteenth century, the so-called "Roman Cement," a natural cement made by calcining and grinding nodules of clayey lime carbonate, called "septaria," found in the clay, was introduced by Joseph Parker. About this time natural cement was manufactured in France. The first natural cement made in the United States was that manufactured for use in the building of the Erie Canal. It came from a natural rock in New York State, Madison County, and was introduced by Canvas White in 1818. The increase in its use was steady from that time until about 1900, since which date there has been a decline in the output, caused by the reduction in cost and consequent increase in use of American Portland cement. The production of natural cement in 1906 was 4,055,797 barrels, valued at $2,423,170, and declined as compared with the output of the preceding year. The industry fluctuated between a production of 7,000,000 and 8,000,000 barrels from 1900 to 1904, when it fell to a little more than 4,500,000 barrels. In 1905 it decreased to a little less than 4,500,000 barrels.

160. DISTRIBUTION OF NATURAL CEMENTS IN THE UNITED STATES.—"In no other country in the world is there to be found cement rock formations which are at all to be compared with those so well distributed throughout the United States. . . . Here we have immense beds of cement rock absolutely free from any extraneous substances, perfectly pure and clean, with layer upon layer, extending for thousands of feet without appreciable variation in the proportion of the ingredients."*

There is a very wide distribution throughout the United States, geologically and geographically, of clayey limestones whose chemical

* Uriah Cummings in the *Brickbuilder*.

composition is such that they may be used in the manufacture of natural cement, and this product has been made, in small or large amounts, and at different periods, in almost every State in the Union. But in order that a natural cement industry may become well established in any given locality, the rock must be fairly steady in chemical composition throughout the strata, the material must be cheaply mined or quarried, the cost of fuel must not be too high, freight must be reasonable and a steady local demand prevail. It is the absence of these requisites in many districts where there are valuable natural cement rock deposits which explains the reason for the relatively few localities in which this industry has become concentrated.

The cement is commonly known by the name of the place from which the stone is obtained, although, as there are often several manufactories in the same locality, there may be several brands of cement made from the same rock. The difference in the quality of such brands is often due to the care exercised in their manufacture.

The principal localities arranged by States in which natural cements are made in the United States are as follows: *

New York.—"In the State of New York natural cement is manufactured in four localities. In the order of their importance they are: (1) the Rosendale district in Ulster County, (2) the Akron-Buffalo district in Erie County, (3) the Fayetteville-Manlius district, for the most part in Onondaga County, and (4) at Howe's Cave in Schoharie County."

The term, "Rosendale Cement," has been heard in New York and New England more frequently than the term "Natural Cement," because Rosendale, Ulster County, N. Y., was one of the towns in which this cement was first made. As a matter of fact, for a time, all natural cements in the United States were called "Rosendale Cement." Owing to the length of time for which it has been used, and the special advantages enjoyed for transportation and nearness to the great building centers of the country, Rosendale cement has perhaps been more widely known than any other of the natural cements. The New York cements are generally of a very good quality and well suited for building operations.

Indiana-Kentucky.—"The plants of the 'Louisville district' are for the most part located in Indiana, though one or two mills are in operation on the Kentucky side of the Ohio River." It is probably the leading natural cement beyond the Alleghenies, the product being exceeded only by the production from New York State. There are several brands of this cement in the market, and they find their way as far west as the Rocky Mountains.

Illinois.—Near Utica, La Salle County, Illinois, a natural cement has

* For a very complete account of the distribution of the American Natural-cement Rocks, and detailed analyses of the same, see "Cements, Limes and Plasters," by Edwin C. Eckel.

been manufactured since 1838. This cement has always stood well in public favor, and is largely used throughout the West.

Wisconsin.—"Two plants in Wisconsin are engaged in the manufacture of natural cement from a clayey magnesian limestone, located north of Milwaukee, near the Lake."

Minnesota.—A cement rock of good quality exists at Mankato, and the manufactured product has obtained a foothold in the markets of the Northwest. There is a second plant located at Austin.

Georgia.—"Two natural cement plants are located in Northwest Georgia, but they use cement rocks from two different geological formations, and their raw materials and products differ widely in composition." The cement manufactured from stone quarried at Cement, Bartow County, "probably has no superior in this country. Used as an exterior plaster on a house in Charleston in 1852, the stucco still remains unimpaired, while the sandstone lintels over the windows have long since been worn away."

Kansas.—A natural cement has been manufactured near Fort Scott since 1867. A bed of natural cement rock, 4½ feet thick, outcrops at this place. It is a dark-colored, fine-grained, compact limestone of the Carboniferous age, and extends for a considerable distance throughout the State.

North Dakota.—A 10-foot bed of soft, chalky limestone rock of the Cretaceous age is being mined for a natural cement plant located in Cavalier County.

Ohio.—At different points in Ohio, notably at Defiance and New Lisbon, there are some small natural cement plants. At the former plant a black calcareous shale of the Devonian age is used, and in regard to this Mr. Edwin C. Eckel states in his "Cements, Limes and Plasters" that if published analyses be correct, this rock is by far the most argillaceous material used anywhere for this purpose.

Texas.—Two natural cement plants have been started in Texas, but the analyses published would seem to show that the product obtained by burning a rock of the chemical composition indicated would be a weak hydraulic lime and not a true natural cement, according to the classifications at present in use.

An extended description of the natural cements manufactured in this country prior to 1895 was given in a series of articles by Uriah Cummings in the *Brickbuilder* for that year.

161. EUROPEAN NATURAL CEMENTS.—These are manufactured in almost all the countries of Europe, but as the products are inferior to the little less costly Portland cement, the latter are gradually driving them out of the market. They also have to compete with the better class of hydraulic limes.

European natural cements may be divided into two classes, called respectively (1) "Natural Portland Cements" and (2) "Roman Cements."

(1) The European natural Portland cements are made from a natural rock and have a small percentage of magnesia. They are burned at a fairly high temperature, and as regards their physical properties and chemical analysis, they are somewhat similar to the true Portlands. But as they are not very carefully and finely ground artificial mixtures made before burning, and will not pass any but the low-grade Portland tests, they cannot be classed with the true Portland cements.

(2) The Roman cements form a second class of European natural cements, and they usually, although not always, have a relatively low percentage of magnesia in their chemical composition. In some respects these products approach the best of the American natural cements, at least as far as their "cementation index" is concerned. In Belgium a quick-setting cement, called a "Roman Cement," is one of the especial products of the immense quarries in the calcareous district of Tournai. In England, stones which burn naturally to cements are to be found to a large extent in certain districts, notably as rounded lumps or nodules of clayey lime carbonate, and called "septaria." These nodules are embedded in the clay of the south of England, in the shale beds of the Lias formation, and along the coast where they have been washed out of the beds.

The Roman cement sets very rapidly, usually in about fifteen minutes after mixing; has about one-third the strength of true Portland cement; and is much weakened by the addition of sand, which should never be used in a greater ratio than 1 to 1.

In speaking of the subject of American and European "Natural Cements," Professor J. B. Johnson in his treatise on "The Materials of Construction" says: "There are few suitable rocks in Europe for making this cement. It is extremely irregular in composition, and not to be compared with the very uniform beds found in inexhaustible quantities in the United States. If such natural cement rocks as we have had been common in England and on the Continent, it is almost certain that the artificial Portland cement would never have been discovered."

162. CHEMICAL ANALYSIS OF SOME AMERICAN NATURAL CEMENTS.—The following table, giving the chemical constituents of some of the American natural cements, will be found useful in comparing the products from different localities:

TABLE X.

Table of Analyses—Natural Rock Cements.

NUMBER.	SILICA.	ALUMINA.	IRON OXIDE.	LIME.	MAGNESIA.	POTASH AND SODA.	CARBONIC ACID, WATER.
1..........	24.30	2.61	6.20	39.45	6.16	5.30	15.23
2..........	34.66	5.10	1.00	30.24	18.00	6.16	4.84
3..........	23.16	6.33	1.71	36.08	20.38	5.27	7.07
4..........	26.40	6.28	1.00	45.22	9.00	4.24	7.86
5..........	25.28	7.85	1.43	44.65	9.50	4.25	7.04
6..........	30.84	7.75	2.11	34.49	17.77	4.00	3.04
7..........	27.30	7.14	1.80	35.98	18.00	6.80	2.98
8..........	28.38	11.71	2.29	43.97	2.21	9.00	2.44
9..........	27.69	8.64	2.00	42.12	14.55	2.00	3.00
10..........	24.34	8.56	2.08	61.62	0.40	2.00	0.80
11..........	23.32	6.99	5.97	53.96	7.76	....	2.00
12..........	27.60	10.60	0.80	33.04	7.26	7.42	2.00
13..........	33.42	10.04	6.00	32.79	9.59	0.50	7.66
14..........	22.58	7.23	3.35	48.18	15.00	....	3.66
15..........	26.61	10.64	3.50	42.12	13.12	2.00	2.01
16..........	25.15	8.00	3.28	49.53	13.78	....	0.26

REFERENCE.

1. Buffalo Hydraulic Cement, Buffalo, N. Y.
2. Utica Hydraulic Cement, Utica, Ill.
3. Milwaukee Hydraulic Cement, Milwaukee, Wis.
4. Louisville Hydraulic Cement, "Fern Leaf," Louisville, Ky.
5. Louisville Hydraulic Cement, "Hulme," Louisville, Ky.
6. Rosendale Hydraulic Cement, "Brooklyn Bridge," Rosendale, N. Y.
7. Rosendale Hydraulic Cement, "Hoffman," Rosendale, N. Y.
8. Cumberland Hydraulic Cement, Cumberland, Md.
9. Akron Hydraulic Cement, "Cummings," Akron, N. Y.
10. California Hydraulic Cement, South Riverside, Cal.
11. Fort Scott Hydraulic Cement, "Brockett's Double Star," Fort Scott, Kansas.
12. Utica Hydraulic Cement, La Salle, Ill.
13. Shepherdstown Hydraulic Cement, Shepherdstown, W. Va.
14. Howard Hydraulic Cement, "Howard," Cement, Ga.
15. Mankato Hydraulic Cement, Mankato, Minn.
16. James River Hydraulic Cement, Balcony Falls, Va.

163. THE MANUFACTURE OF NATURAL CEMENT.—From a mechanical standpoint, the manufacture of natural cement is a comparatively simple process, and especially when compared to that of Portland cement. It involves only two general operations, burning and grinding.

It is not the province of a work on Building Construction to go into detail regarding the manufacture of building materials, and for full descriptions of the processes of cement burning and grinding the reader is referred to the many recent treatises on Limes, Cements, Mortars and Concretes. At this point, however, a very brief enumeration of the steps followed in making natural cement may be useful.

The limestone is usually stratified, the strata varying somewhat in chemical composition, but the rock, in its natural state, contains the proper ingredients for natural cement. For any given brand of cement it is usual to mix several strata, so that in case there is too much silica in one layer, it will be corrected by another containing a surplus of lime or magnesia. The principal steps in order in the process of manufacture are as follows:

1. Quarrying the rock, (*a*) in open cuts, or (*b*) by mining in tunnels and chambers.

2. Breaking the rock into sizes convenient for handling.

3. Running the rock through an ordinary rock-crusher, and breaking it into pieces varying in size up to six inches, greatest dimension.

4. Carrying the rock, generally by tramway, to the platforms at the top of the kilns, which are usually of the "vertical continuous mixed-feed type," averaging 45 feet in height and 16 feet in diameter, and built either (*a*) of masonry lined with fire-brick, or (*b*) of an iron shell, lined with fire-brick.

5. Spreading the rock and fuel in the kiln in alternate layers, the fuel being (*a*) anthracite coal, or (*b*) a good quality of bituminous coal.

6. Burning the rock and fuel, the temperature being "somewhat greater than that used for burning lime, but below the point of incipient fusion reached in burning Portland cement."

7. Sorting out and throwing away the underburnt and overburnt clinker, necessitated by the inevitable non-uniform burning, and resulting in a "probable average loss of about 25 per cent."

8. Conveying the sorted calcined rock to crushing machines, usually "pot-crackers."

9. Conveying the crushed material to screens which separate the coarse particles from the cement that is fine enough to pack.

10. Grinding the coarser particles in the fine grinding machines,

usually either (*a*) "edge-runners," or (*b*) ball or tube-mills, or (*c*) ordinary mills, or (*d*) emery-faced stones.

11. Passing the product through the mixers to obtain greater uniformity.

12. Conveying the product by chutes to the packing rooms, and packing it in bags and barrels.

164. THE USES OF NATURAL CEMENTS.—As the use of lime mortar is confined to dry places where it is exposed to the air, being usually employed only in the construction of thin walls above ground and in the foundation coats of plaster; and as it loses its binding properties when exposed to dampness, as in basement walls, and when excluded from contact with air, as in thick walls; and as it sets too slowly to bear any immediate heavy weight; cements have to be added or cement mortars substituted to meet these conditions.

In mortar, natural cement is adapted to ordinary brickwork not subjected to high water pressure or to contact with water until about one month after laying; and for ordinary stone masonry where the chief requisites are weight and mass.

Natural cement mortar or concrete should never be allowed to freeze, should never be laid under water, nor in very exposed situations, nor in marine construction.

Natural cement may be substituted for Portland in concrete, if economy demands it, for dry unexposed foundations where the load in compression can never exceed about 75 pounds per square inch (5 tons per square foot) and will not be exposed until three months after placing; for backing or filling in massive concrete or stone masonry where weight and mass are the essential elements; for subpavements of streets and for sewer foundations.

Messrs. Taylor and Thompson in their treatise on concretes state that "mixtures of natural and Portland cements, unless mixed at the factory and sold as improved natural hydraulic cements, are not advised under any conditions.

"Mixtures of natural cement and lime mortar are suitable for ordinary building brickwork, for light rubble foundations and for building walls."*

"Natural, quick-setting cements are used for reinforced concrete only in special forms of construction, viz., in repair work, as when quick setting is necessary in order to enable the structure to sustain

* "Concrete, Plain and Reinforced." Taylor and Thompson.

moderate loads or enable its use within a few hours; in hydraulic work, as in the construction of reservoirs and conduits; and in the construction of reinforced pipe. They are, however, extensively used for plain concrete work. Sometimes, when quick setting with great strength is desired, a mixture of natural and Portland cements is employed."*

"While the better grades of natural cement are quite sufficient in strength for nearly all kinds of engineering works, the want of uniformity in their hardening properties is a serious objection to their use."†

"Natural cement mortar is used in the construction of ordinary walls, sewers, foundations for roadways, etc., when Portland is considered too expensive."‡

165. CHARACTERISTIC PROPERTIES AND REQUIREMENTS OF NATURAL CEMENTS.—*Packages.*—Natural cement as well as Portland cement is usually packed in strong cloth or canvas sacks, except in cases where it is to be stored in damp places or near the sea, when it should be packed in well-made wooden barrels lined with paper.

Field Inspection.—A general field inspection often enables a correct judgment to be formed of the condition of the cement, which is generally stored temporarily on raised platforms at the site of the construction, in order that the necessary tests may be made. The general condition and marking of the packages should be observed.

Sampling.—For the purpose of testing, samples are taken from the packages at random. There are different methods of sampling. Sometimes each sample from each package is tested separately, and sometimes small samples are taken from each of a number of packages, mixed together, and then separated again into convenient sample lots for testing.

Color.—The color of cement is no criterion of quality. In a natural cement it may indicate the uniformity or non-uniformity of a given brand or grade, or differences in the composition of the rock used, or in the degree of burning. There is a great variation in color among the natural cements, and they run from a light yellow to a dark gray and sometimes to a chocolate-brown. The color gives no clue to the cementitious value, since it is due chiefly to

* "Concrete, and Reinforced Concrete Construction." Homer A. Reid.
† "The Materials of Construction." J. B. Johnson.
‡ "Civil Engineering." C. J. Fiebeger.

oxides of iron and manganese, which bear no direct relation to the cementing properties. A very light color often may indicate, however, an inferior underburned natural cement.

Weight.—The specifications of the American Society for Testing Materials require the packing in bags of 94 pounds, net, three bags constituting a barrel of 282 pounds. A cement bag weighs about one pound. In different localities, however, different standards of weight prevail. The standard barrel of natural cement weighs about 320 pounds gross or 300 pounds net in the Rosendale, Howe's Cave, and Akron districts; 300 pounds gross and 280 pounds, net, in the Lehigh district of Pennsylvania; and 280 pounds gross or 265 pounds, net, in the Louisville, Utica, Milwaukee, Fort Scott and other western districts. Again, these rules have exceptions, the Howard cement of Georgia, for example, weighing only about 240 pounds to an Eastern natural cement barrel, and the Pembina cement of North Dakota weighing 380 pounds net per barrel. The latter cement is packed at about the regular Portland cement weight.

The average weight of Louisville or Rosendale cement is, per cubic foot, loose, 50 to 57 pounds; and per cubic foot, packed, from 74 to 80 pounds.

Specific Gravity.—The specific gravity of a cement in general gives an indication of the thoroughness of burning, as it is lowered by underburning and raised by overburning. It is also lowered by hydration and adulteration. This test supplements the chemical analysis, since the latter does not indicate the degree of calcination. The specific gravity of natural cement is generally no criterion of its quality, but, to some degree, may be regarded as a measure of the uniformity of a single grade. The usual specification requires that the specific gravity of the natural cement thoroughly dried at 100 degrees Cent. (212 degrees Fahr.) shall be not less than 2.8. Very few American natural cements ever fall as low in specific gravity as 2.8, and they range between 2.8 and 3.2, thus overlapping the lower limit given for Portland cement.

Activity, or Time of Setting.—When water is added to cement, making a paste, the latter gradually hardens, and the rate of hardening is called the "activity" of the cement. The time when the mass begins to harden is called the "initial set," and the time when the mass has become so hard that it cannot be distorted or penetrated without rupture is called the "final set" or "hard set."

Certain definite limits must be fixed for the time of setting, and for natural cement it is usually specified that it shall develop initial set in not less than ten minutes, and hard set in not less than thirty minutes, nor in more than three hours. For full descriptions of the apparatus and methods used to determine the time of set, the reader is referred to the treatises on Cement Testing, especially to "Practical Cement Testing," by W. Purves Taylor.

The natural cements are generally much quicker in setting than the Portland cements, although slow-setting natural cements are occasionally met with, and a rapidity of set may be changed by aeration, by the addition of gypsum or plaster, etc.

In case the necessary laboratory apparatus for testing the activity is not at hand, for practical purposes the setting qualities of the cement or mortar may often be examined in ordinary construction, by making up pats from a number of the packages and by the pressure of the thumb testing their hardening. When the surface can no longer be indented, the paste or mortar may be considered to have reached the stage of the final set.

Soundness or Constancy of Volume.—It is the purpose of this test to determine in advance whether or not the cement is apt to disintegrate, to crumble, expand or contract and thus cause cracking or distortion in the masonry. The term "deformation" is employed in France. A cement is said to be "sound" when it does not expand or contract or check in setting. The principal causes of unsoundness are improper mixing, faulty processes of manufacture, excess of lime, insufficient grinding, underburning, the presence of sulphides, an excess of magnesia or of the alkalies, an excess of clay and insufficient age. Tests for soundness are of two kinds: (1) The Normal test, a pat being immersed in water at 70 degrees Fahr. for 28 days, and a similar pat kept in air at ordinary temperatures and observed at intervals, and (2) the Accelerated test, a pat being exposed in any convenient way in an atmosphere of steam above boiling water, in a loosely closed vessel, for 5 hours. This test is usually considered as a corroborative test only, and not as final.

Tests made on pats of neat cement paste kept in air and water under normal conditions are considered to be the only conclusive ones for natural cements. In both natural and Portland cements similar phenomena are noticed in regard to excessive expansion,

checking or disintegration on normal pats. For natural cements the accelerated test has not proved successful.

The usual requirements for constancy of volume of natural cement are as follows: Pats of neat cement about 3 inches in diameter, one-half inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another pat is kept in water maintained as near 70 degrees Fahr. as practicable.

These pats are observed at intervals for at least 28 days, and to satisfactorily pass the tests should remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

Fineness.—The finer a cement of any class is ground the better its quality. The following requirement for the "fineness" of natural cement is taken from the Standard Specifications of the American Society for Testing Materials: "It shall leave by weight a residue of not more than 10 per cent on the No. 100, and 30 per cent on the No. 200 sieve."

The following are some opinions of different engineers and authorities on fineness requirements of cements:

"It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

"The effects of grinding upon cements are to make them,

(1) Stronger when tested with sand;

(2) Weaker when tested neat;

(3) Quicker setting;

(4) Capable of producing a larger volume of paste;

(5) Less affected by free lime.

"With the same proportions of sand higher tensile and compressive strength is obtained from finely ground than coarsely ground cements. Conversely, a larger proportion of sand can be used with fine-ground than with coarse-ground cement, with the same resulting strength."*

"The degree of fineness to which a natural cement is ground depends both upon the composition of the material and the process of grinding used. At times the percentage which will pass a No.

* "Concrete, Plain and Reinforced." Taylor and Thompson.

200 sieve will approximate that for Portland cement. Fine grinding is, however, not as essential in the manufacture of natural as in Portland cement, as the amount of free lime present is much less. If the requirements are such that 85 per cent or more must pass a No. 100 sieve, and 70 per cent or more must pass a No. 200 sieve, a good quality of natural cement should result."*

"Until quite recently the grinding of an American natural cement was rarely carried further than was necessary to pass 95 per cent of the material through a 50-mesh sieve. In only a few cases was a greater fineness demanded than 85 per cent through a 100-mesh sieve. The average requirements, then, were low, and the average cement just about passed requirements.

"Within the past few years some natural cement manufacturers have realized that if the natural cement industry is to be maintained in the face of competition from Portland cement the product must be improved. One of the easiest methods of doing this is to increase the fineness of the grinding. This has the effect of making the cement more sound and of increasing its sand-carrying capacity, and therefore its strength when tested as mortar.

"There are differences in the fineness requirements of several important standard specifications. The requirements of the American Society for Testing Materials (90 per cent through 100-mesh, 70 per cent through 200-mesh) are high, and probably cannot be economically attained unless modern grinding machinery is in use at the mill. With tube mills, however, this fineness can be readily reached, and the tensile strength of the cement is greatly improved."†

166. STRENGTH TESTS.—*For Natural Cements.*—A discussion of the various tests for the strength of different kinds of cements is taken up in the subdivision of this chapter devoted to that subject. At this point, however, it will be well to give some of the standard and recent usual requirements for the tensile strength of natural cements. (See Articles 191, 197 and 208.)

The paragraph relating to the tensile strength of natural cements, in the Standard Specifications of the American Society for Testing Materials, is as follows:

The minimum requirements for tensile strength for briquettes

* "Concrete, and Reinforced Concrete Construction." Homer A. Reid.
† "Cements, Limes and Plasters." Edwin C. Eckel.

1 inch square in cross-section shall be within the following limits, and shall show no retrogression within the periods specified.

Age.	Neat Cement.	Strength.
24 hours in moist air		50-100 lbs.
7 days (1 day in moist air, 6 days in water)		100-200 lbs.
28 days (1 day in moist air, 27 days in water)		200-300 lbs.
	1 part Cement, 3 Parts Standard Sand.	
7 days (1 day in moist air, 6 days in water)		25- 75 lbs.
28 days (1 day in moist air, 27 days in water)		75-150 lbs.

The tensile strength required for natural cements is highly variable in specifications for even large and important works, and these variations are illustrated in the following table:*

TABLE XI.

NATURAL CEMENTS.

STRENGTH REQUIRED BY VARIOUS SPECIFICATIONS.

	Neat			1 : 1	
	1 Day	7 Days	28 Days	7 Days	28 Days
N. Y. State Canals	....	....	....	65 lbs.	125 lbs.
N. Y. Subway	....	125 lbs.	200 lbs.	100 "	150 "
Engineer Corps, U. S. A.	....	90 "	200 "	60 "	150 "
Soc. Testing Materials	50-100lbs.	100-200"	200-300"	25-75* "	75-150*"

*In this specification the mortar mixture is 1 cement, 3 sand.

The following tests belong to a fuller discussion of the whole subject of strength tests of cements and cement mortars: Compressive strength, relation of compressive to tensile strength, transverse or flectural strength, relation of flectural fiber stress to tensile stress, adhesive strength, abrasive or wearing resistance, shearing strength and coefficient of elasticity.

167. SPECIAL TESTS OF CEMENTS AND MORTARS.—The most important tests for comparing the qualities of different cements and for determining their practical value have been mentioned or discussed in the preceding articles. There are certain other tests, which may be merely mentioned here, and which are sometimes made to investigate special qualities of a cement or mortar, or for scientific research. Such, for example, are the tests which are made for porosity, permeability, yield of paste and

*"Cements, Limes and Plasters." Edwin C. Eckel.

mortar, rise of temperature while setting, homogeneity (microscopical) and decomposition.

As compared with the standard tests, such as chemical analysis, specific gravity, fineness, activity or time of setting, tensile strength and soundness or constancy of volume, the special tests above mentioned are usually of minor importance, and for full descriptions of them the reader is referred to the treatises on cement testing.

168. SPECIFICATIONS FOR NATURAL CEMENTS.—Specifications for the cement for any particular operation are based upon the architect's or engineer's own practice, supplemented by a careful study of the model specifications of other recent important works. There is considerable variation in the requirements on various points, and it is useful to compare these different demands, and thus determine the average of good and safe practice.

Several different sets of specifications for natural cements are given in Chapter XIII, "Specifications."

One excellent set is given here, the specifications for natural cement based upon the practice of Engineers F. W. Taylor and S. E. Thompson, supplemented by their careful study of the specifications of the following: American Society for Testing Materials, American Railway Engineering and Maintenance-of-Way Association, City of Philadelphia, United States Army, United States Navy, Massachusetts Metropolitan Commissions, New York Rapid Transit Commission, and others.

1. *Packages.*—Cement shall be packed in strong cloth or canvas sacks.† Each package shall have printed upon it the brand or the name of the manufacturer. Packages received in broken or damaged condition may be rejected or accepted as fractional packages.

2. *Weight.*—Three bags shall constitute a barrel, and the average net weight of the cement contained in one bag shall not be less than 94 pounds, or 282 pounds net per barrel. A cement bag may be assumed to weigh one pound. The weights of the separate packages shall be uniform.

3. *Requirements.**—Cement failing to meet the seven-day requirements may be held awaiting the result of the twenty-eight-day tests before rejection.

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* Paragraphs designated by an asterisk are quoted from the Standard Specifications of the American Society for Testing Materials.

†If the cement is to be stored in a damp place or near the sea, it must be packed in well-made wooden barrels lined with paper.

4. *Tests.**—All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the Society January 21, 1903, and amended January 20, 1904, with all subsequent amendments thereto.

5. *Sampling.*—Samples shall be taken at random from sound packages, and the cement from each package shall be tested separately.

6.* The acceptance or rejection shall be based on the following requirements:

7. *Definition of Natural Cement.**—This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas.

8. *Specific Gravity.**—The specific gravity of the cement thoroughly dried at 100 degrees Cent. (212 degrees Fahr.) shall be not less than 2.8.

9. *Fineness.**—It shall leave by weight a residue of not more than 10 per cent on the No. 100, and 30 per cent on the No. 200 sieve.

10. *Time of Setting.**—It shall develop initial set in not less than ten minutes, and hard set in not less than thirty minutes, nor more than three hours.

11. *Tensile Strength.*—Briquettes one inch square in section shall attain at least the following tensile strength and shall show no retrogression within the periods specified.

NEAT CEMENT.

Age.	Strength.†
24 hours in moist air	50 lbs.
7 days (1 day in air, 6 days in water)	100 lbs.
28 days (1 day in air, 27 days in water)	200 lbs.

ONE PART CEMENT, THREE PARTS STANDARD SAND.

Age.	Strength.†
7 days (1 day in air, 6 days in water)	25 lbs.
28 days (1 day in air, 27 days in water)	75 lbs.

12. *Constancy of Volume.**—Pats of neat cement about 3 inches

*Paragraphs designated by an asterisk are quoted from the Standard Specifications of the American Society for Testing Materials.

†The American Society for Testing Materials gives minimum requirements as follows: Neat Cement—24 hrs., 50-100 lb.; 7 days, 100-200 lb.; 28 days, 200-300 lb.; 1:3 mortar—7 days, 25-75 lb.; 28 days, 75-150 lb.; the exact values to be fixed in each case by the consumer.

in diameter, one-half inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another pat is kept in water maintained as near 70 degrees Fahr. as practicable.

These pats are observed at intervals for at least 28 days, and to satisfactorily pass the tests should remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

169. MISCELLANEOUS DATA AND MEMORANDA, PRINCIPALLY ON NATURAL CEMENTS.—"Cement is shipped in barrels or in cotton or paper bags. The usual dimensions of a barrel are: length, 2 feet 4 inches; middle diameter, 1 foot 4½ inches; end diameter, 1 foot 3½ inches.

"The bags hold 50, 100 or 200 pounds.

"A barrel weighs about as follows:

Rosendale, N. Y.	300 lbs. net.
Rosendale, Western	265 lbs. net.
Portland	375 lbs. net.

"A barrel of Rosendale cement contains about 3.40 cubic feet and will make from 3.70 to 3.75 cubic feet of stiff paste, or 79 to 83 pounds will make about one cubic foot of paste.

"A barrel of cement measured loosely increases considerably in bulk. The following results were obtained by measuring in quantities of two cubic feet:

1 bbl. Norton's Rosendale gave	4.37 cu. ft.
1 bbl. Anchor Portland gave	3.65 cu. ft.
1 bbl. Sphinx Portland gave	3.71 cu. ft.
1 bbl. Buckeye Portland gave	4.25 cu. ft.

"The weight of cement per cubic foot is as follows:

Portland, English and German	77 to 90 lbs.
Portland, fine-ground French	69 lbs.
Portland, American	92 to 95 lbs.
Rosendale	49 to 56 lbs.
Roman	54 lbs.

"A bushel contains 1.244 cubic feet. The weight of a bushel can be obtained sufficiently close by adding 25 per cent to the weight per cubic foot."*

* "Inspector's Pocket Book." A. T. Byrne

The following data bearing upon the above, and showing slight variations, are taken from another authority:*

Portland cement weighs per barrel, net	376 lbs.
Portland cement weighs per bag, net	94 lbs.
Natural cement weighs per barrel, net	282 lbs.
Natural cement weighs per bag, net	94 lbs.
Cement barrel weighs from 15 to 30 lbs., averaging about	20 lbs.
Portland cement is assumed in standard proportioning to weigh per cubic foot	100 lbs.
Packed Portland cement, as in barrels, averages per cubic foot about	115 lbs.
Packed Portland cement, based on 3.5 cubic feet barrel contents, weighs per cubic foot	108½ lbs.
Loose Portland cement averages per cubic foot about	92 lbs.
Volume of cement barrel, if cement is assumed to weigh 100 lbs. per cubic foot	3.8 cu. ft.
American Portland cement barrel averages between heads about	3.5 cu. ft.
Foreign Portland cement barrel averages between heads about	3.25 cu. ft.
Natural cement barrel averages between heads about	3.75 cu. ft.

The additional data in this article, useful in estimates of cement work, are added with the accompanying explanatory note:†

"The following estimates of quantities are simply approximate and may be exceeded or not attained, according to the local circumstances. While most of them are the results of actual experiment under practical conditions, the writer has checked but few of them in his practice, and presents them as being correct under a single set of conditions only, and approximately so in others. For rough estimates they will answer satisfactorily. Each engineer or contractor is soon able to estimate his own quantities under the conditions of the methods he adopts better than he can from any statements of average results.

Packing and Shipping Cement.

Cement is packed in barrels, cloth sacks or paper bags, as ordered.

A barrel of Portland cement weighs about 400 pounds gross, and should contain 380 pounds net of cement.

Portland cement, loose, weighs 70 to 90 pounds per cubic foot; packed, about 110 pounds per cubic foot.

A barrel of eastern natural hydraulic cement weighs about 320 pounds gross and should contain 300 pounds net of cement.

A barrel of western natural hydraulic cement weighs about 285 pounds gross and should contain 265 pounds net of cement.

* "Concrete, Plain and Reinforced." Taylor and Thompson.
† "Handbook for Cement Users." Charles C. Brown.

Natural hydraulic cement, loose, weighs about 50 to 57 pounds per cubic foot; packed, about 80 pounds per cubic foot. Weights of cement and volumes of barrels are not uniform. Nearly all natural hydraulic cement is sold in sacks.

Slag cement weighs about 350 pounds gross, or 330 pounds net.

Cloth sacks ordinarily contain one-third of a barrel of natural hydraulic cement. The standard for Portland cement is one-fourth of a barrel. Paper sacks contain one-fourth of a barrel.

The following on cement packages is from a circular issued by a firm of general agents for cement:

Four paper bags or four cloth bags constitute one barrel or 380 pounds of Portland cement. The paper bags are charged to the customer at 2½ cents each or 10 cents per barrel, and are of no further value. They have served their purpose in carrying the cement to destination and have given you service that is worth 10 cents per barrel. The cloth bags are charged at 10 cents each or 40 cents per barrel, and are worth 10 cents each or 40 cents per barrel if returned and received, freight paid, in good condition at the mill.

Here has been the misleading part to the consumer. While a few paper bags are liable to be broken in transportation with a corresponding loss of cement, the minimum loss of cement in a cloth bag is one pound to the sack or four pounds to the barrel. This amount remains unshaken from the bag. We have seen laborers so careless as to waste 3 per cent of their cement in this manner. A paper bag is more easily handled—can be emptied with absolutely no loss of cement. It takes time to untie a cloth bag and time costs money. A paper bag can be cut open with a hoe instantly.

The manufacturers and the railroads require bags returned to be freight prepaid. The minimum expense of such transportation from this district is 1¼ cents per barrel, which you pay. Use paper and save it.

The table on page 159 from *The Engineering News* gives an idea of the variation in size of cement barrels. The first three brands named are American and the other two foreign Portland cements.

A carload of Portland cement usually means 100 barrels (40,000 pounds); 75 barrels is the minimum carload, or the same quantity by weight in cloth or paper bags.

When cement is ordered in cloth sacks the sacks are charged at cost, viz.: 10 cents each, in addition to the cost of the cement; but when the sacks are returned to the works in good condition, freight

TABLE XII.

TABLE SHOWING VARIATIONS IN SIZES OF CEMENT BARRELS.

Portland cement brand	(1) Capacity of bbl. cubic feet	(2) Actual contents, packed measure	(3) Volume when dumped loose	Difference between (1) and (2)	Difference between (2) and (3)
Giant	3.5	3.35	4.17	4%	25%
Atlas	3.45	3.21	3.75	4"	18"
Saylors	3.25	3.15	4.05	3"	30"
Alsen	3.22	3.16	4.19	2"	33"
Dyckerhoff	3.12	3.03	4.00	3"	33"

prepaid, 10 cents is allowed for each, with a deduction of 2 cents for wear and tear in some cases.

For paper bags there is no charge, as they are not apt to be returned.

Empty sacks to be returned should be safely tied in bundles of ten or fifty, giving the name of the sender."

170. THE CHOICE OF CEMENTS, AND THE SELECTION OF BRANDS.—The question often arises as to whether natural cement or Portland cement is the more desirable from an economic standpoint, aside from considerations of strength and other properties. Local conditions generally decide the question. There are some general rules of good engineering practice which have been formulated, and which relate to the classes of construction for which different kinds of cement and lime are best adapted. These classes have already been mentioned in regard to the uses of natural cement mortar, for example, under that heading. (See Article 164.)

If the architect or engineer decides that in a certain structure either natural cement or Portland cement may be used, the relative cost decides the choice, and the cost in turn depends upon the proportions of cement and sand that may be adopted in either case.

The usual proportions for natural cement mortar are 1:2, that is, one part of cement to two parts of sand, by volume, while in Portland cement mortar the sand is, up to a certain point, only limited by practical considerations, such as the handling of the cement with the trowel, and goes to the proportions 1:3 and 1:4.

After assuming the proportions of the two classes of mortar, the relative cost is governed principally by the quantity of cement in a cubic yard of mortar. It can be shown that Portland cement

mortar made of one part cement to four parts sand is equivalent in cost to natural cement mortar made of one part cement to two parts sand, when Portland cement delivered on the job costs 68 per cent more than natural cement, or when the former, for example, costs $1.68 per barrel, and the latter $1.00 per barrel.

About 10 per cent more of bricks can be laid in a given time with natural cement mortar when the proportions are 1:2 than with Portland cement mortar with the proportions, for example, of 1:3; consequently when the cost of Portland and natural cement is the same, the natural cement produces the brickwork for less money. It has been estimated that in some cases there is a difference of 30 cents per barrel of cement corresponding to the difference in the labor of laying bricks; and it has also been shown that Portland cement mortar can seldom be substituted for natural cement mortar without an increase in the cost of the work.

In regard to the selection of any particular brand from a number of different brands of the same class of cements, such as natural cements, for example, the architect or engineer must be guided by experience, by the history and reputation of that special brand, or by thorough laboratory tests. Between two cements which are "sound," and which set properly, the choice can usually be made by selecting the one which shows the greater fineness when tested with two sieves, as already described. The stronger mortar is usually produced by the finer cement.

The cheapest cement is not always the most economical. Tables have been made to show the relative economy of cements offered by bidders at different prices, especially for government work. The final selection is made after careful consideration of all the data referring to each brand, such as the relative tensile strength of the mortars of certain proportions of cement to sand, the products of the relative strength by the relative cheapness, the soundness, the volumes of the barrels, their gross net weights, the percentages of water used in mixing the pastes and mortars, the time of setting of the mortar, and the strength and relative economy of mortars with sand proportioned to the price of each cement.*

"The difficulties which are encountered in the attempt to discuss the natural cements as a class, laying emphasis upon the points of resemblance of the various brands and disregarding for the time

*For a full discussion of the subjects of "The Choice of Cement," and "The Selection of the Brand," see "Concrete, Plain and Reinforced," by Taylor and Thompson.

their many points of difference, are greater than the reader, at first sight, may imagine; for few engineers realize what a heterogeneous collection of products is included under the well-known name of 'natural cement.' The cause for this lack of knowledge is not far to seek. Natural cements are too low in value to be shipped, under ordinary circumstances, far from their point of production. The natural cement made at any given locality has usually, therefore, a well-defined market area within which it is well known and subject to little competition. The engineer practicing within such an area naturally forms his idea of natural cements in general from what he knows of the brands encountered in his work, and as all the brands from one cement-producing locality are apt to resemble one another quite closely, he is likely to conclude that natural cements are quite a homogeneous class, with many points of resemblance and few of difference. The truth is, on the contrary, that there may be far greater differences of strength, rate of set, chemical composition, etc., between the natural cement made in two different localities than between any given brand of natural cement and a Portland cement."* See also Art. 182, "The Choice of Portland Cement, and the Selection of Brands."

4. PORTLAND CEMENTS.

171. PLACE OF PORTLAND CEMENT IN THE CLASSIFICATION.—The classification of cementing materials has already been considered under that heading in Article 157, and Portland cement is the fourth of the five divisions mentioned. It belongs to the group of hydraulic cements, and is perhaps now the most important of the cementing materials.

Having considered the common limes, the hydraulic limes and the natural cements, the Portland cements will be considered in the following articles.

Reference to Table IX, in Art. 157, will make clear the position of Portland cement in the classification, and show the comparison of this with other cementing materials in the typical analyses given.

172. DEFINITIONS OF PORTLAND CEMENT.—The following is the definition given in the Standard Specifications of the American Society for Testing Materials: "This term applies to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned

* "Cements, Limes and Plasters." Edwin C. Eckel.

argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination."

The term "argillaceous" means clayey, and "calcareous" means consisting of lime or calcium.

The definition in the specifications of the Engineer Corps, U. S. Army, 1902, is as follows:

"By a Portland cement is meant the product obtained from the heating or calcining up to incipient fusion of intimate mixtures, either natural or artificial, or argillaceous with calcareous substances, the calcined product to contain at least 1.7 times as much of lime, by weight, as of the materials which give the lime its hydraulic properties, and to be finely pulverized after said calcination, and thereafter additions or substitutions for the purpose only of regulating certain properties of technical importance to be allowable to not exceeding 2 per cent of the calcined product."

Another definition is:

"Portland cement is a hydraulic cementing material with a specific gravity of not less than 3.10 in the calcined condition, and containing not less than 1.7 parts by weight of lime to each one part of silica + alumina + iron oxide, the material being prepared by intimately grinding the raw ingredients, calcining them to not less than clinkering temperature, and then reducing to proper fineness."

Mr. Edwin C. Eckel, of the U. S. Geological Survey, believes that the following definition will be found more satisfactory than those now in use for insertion as a preliminary requirement in cement specifications:

"By the term Portland cement is to be understood the product obtained by finely pulverizing clinker produced by burning to semi-fusion an intimate artificial mixture of finely ground calcareous and argillaceous materials, this mixture consisting approximately of three parts of lime carbonate (or an equivalent amount of lime oxide) to one part of silica, alumina and iron oxide. The ratio of lime (Ca O) in the finished cement to the silica, alumina and iron oxide together shall not be less than 1.6 to 1, or more than 2.3 to 1."

The question of the definition of Portland cement for specifications is an important one, as there has been only a partial and not a complete agreement as to what is to be understood by the term. The principal difference of opinion is in regard to the question of including or not including among the true Portlands those cements made by burning a natural rock without previous mixing and grind-

ing, and any definition based upon such criteria would exclude some products manufactured in France and Belgium called "natural Portlands." Also, in regard to American-made Portland cements, it is considered by some of the highest authorities a serious error to omit from specifications the requirement relating to the pulverizing or artificial mixing of the materials prior to burning, because at present there are no true Portland cements manufactured in America from natural mixtures without such preliminary pulverizing and artificial mixing.

173. THE EARLY HISTORY AND USE OF PORTLAND CEMENT.—Joseph Aspdin, a brickmaker of Leeds, England, invented Portland cement and took out a patent in 1824 on the manufacture of a product resulting from the calcination of an artificial mixture of pulverized limestone and clay. It was first patented as an "artificial stone." To this product was given the name "Portland," from a fancied, though really slight resemblance of the cement after it has set to the noted oolitic limestone from the Isle of Portland, a peninsula on the south coast of England, in Dorset, near Weymouth. This stone, well known to all English architects and engineers as "Portland Stone," was much used in England at that time, and a recent prominent example of its use is the London Westminster Cathedral, where it appears in bands in the red brickwork.

It was not until about twenty years after the discovery by Aspdin that the Portland cement industry was developed to any great extent, when J. B. White & Sons, in Kent, England, began its manufacture, and when a little later Mr. John Grant, an eminent English engineer, made important tests and used the cement extensively on the London drainage works.

In France the first manufactory for producing Portland cement was established at Boulogne-sur-Mer toward the middle of the last century.

In Germany, soon after the first production of the cement in France, the first factories were built for the production of the Stettin brands. Although for a time England led in the manufacture of Portland cement, Germany afterward took the lead, and with such success that for a while it was the foremost country in the amount produced, in 1900 passing all other countries.

The United States during the past few years has surpassed all other countries in the manufacture of Portland cement. Mr. David

O. Saylor, of Coplay, Pa., in the Lehigh Valley, was the founder of this industry in America. He made his first discoveries in 1874 and 1875, and built his first factory in 1878. During the first fifteen years the development of the industry was exceedingly slow, but about the year 1890 it took a new start and since then has been very rapid.

174. THE PRESENT USE OF PORTLAND CEMENT.—Good Portland cement is constantly finding wider and wider fields of application. It has been said that it has already worked a revolution in engineering and architectural construction nearly equal in significance to that following upon the general use of the Bessemer and open-hearth processes of making steel. In its production its quality is being constantly improved, a result largely due to the excellent systems of testing, and to the consequent necessity of employing at the works the most competent scientific supervision. It is now made on a gigantic scale in the United States, Germany, Belgium, the United Kingdom and France.

In 1890 only 335,500 barrels of Portland cement were manufactured in the United States; but since that time the development of the industry has been so rapid that in 1905 the number of barrels reached a grand total of 35,246,812, and of this total over one-half was produced in the Lehigh district of Pennsylvania and New Jersey. In 1906 the output was 46,463,424 barrels, valued at $52,-466,186, and the estimated output for 1907 is 48,000,000 barrels. Existing American plants have now (1908) a total capacity of about 60,000,000 barrels a year.

The wonderful rapidity of the development of the manufacture of Portland cement, and the increase in the amount of this cement produced from about the year 1880 to the present time, may be best understood by an examination of the tables compiled and published by the government and by the most recent treatises on building materials of this nature. It is not possible in this brief chapter to insert these tables, and the reader is referred to such authoritative data as, for example, the annual reports on the "Mineral Resources of the United States," issued by the United States Geological Survey, and to various compilations made from these reports, found in recent exhaustive works on limes, cements, mortars and concretes. Such are the tables on "Total Production of Portland Cement in the United States from 1870 to Date," "Production of Portland Cement

in the United States for the Different Years by States," "Distribution of the Manufacture of Portland Cement and the Development in the Various Regions," "Portland Cement Production of the Lehigh District of Pennsylvania-New Jersey," "Imports of Cement into the United States by Years, and by Countries," "Total Consumption of Natural Cement, Imported Portland Cement, Domestic Portland Cement and Puzzolan Cement in the United States in Barrels, and the Annual Percentages of Each Class," "Consumption of Cement in the United States per Capita of Population," "Exportation of Cement from the United States," and "Diagrams Showing Graphically Changes in Percentages of Natural Cement and Imported and American Portland Cement Used Each Year."

175. CHEMICAL ANALYSIS OF PORTLAND CEMENTS.—The definitions of Portland cement have already been given in Article 172. A Portland cement mixture, when ready for burning, should contain about 75 per cent of lime carbonate ($CaCO_3$), and about 20 per cent of silica (SiO_2), alumina (Al_2O_3) and iron oxide (Fe_2O_3) together, the remaining 5 per cent or so containing any magnesia, sulphur and alkalies that may be present. There is an abundant and wide distribution in nature of lime, silica, alumina and iron, which occur in various kinds of rocks in different forms.

Mr. Edwin C. Eckel analyzes the various raw materials available for use in Portland cement manufacture as follows: He states that as to *composition*, they may be (a) purely calcareous, (b) a mixture

TABLE XIII.*

CHARACTER OF PORTLAND CEMENT MATERIALS.

	Natural			Artificial
	Hard	Soft	Unconsolidated	Unconsolidated
Calcareous ($CaCO_3$ over 75%)	Pure hard limestone	Pure soft limestone or pure chalk	Pure marl	Alkali waste
Argillo-calcareous ($CaCO_3$ 40 to 75%)	Hard clayey limestone (cement rock)	Soft limestone or clayey chalk	Clayey marl	Blast-furnace slag
Argillaceous ($CaCO_3$ less than 40%)	Slate	Shale	Clay	

* "Cements, Limes and Plasters." Edwin C. Eckel.

of calcareous and argillaceous elements, or (c) almost purely argillaceous; as to *physical character* they may be (a) hard and massive, like the hard limestones and slates, (b) soft, like the chalks and shales, or (c) granular or unconsolidated, like the marls, clays, alkali waste and granulated slag. As to *origin,* they may be (a) natural, like limestones, marls, slates, clays, etc., or (b) artificial, like alkali waste and furnace slag.

The same writer in various valuable papers published at different times has grouped, under six heads, the various combinations of raw materials at present used in the United States in the manufacture of Portland cement:

(1) Argillaceous hard limestone (cement rock) and pure limestone.

(2) Pure hard limestone and clay (or shale).

(3) Soft (chalky) limestone and clay (or shale).

(4) Marl and clay (or shale).

(5) Alkali waste and clay.

(6) Slag and pure limestone.

The materials vary with the locality. In the Lehigh district the chief raw materials used are cement rock and limestone, and the Virginias, Alabama, Colorado and Utah have similar formations; in the New York State Eastern cement region and in California and occasionally in the Central States, limestone and clay; in Western New York and in the Middle West, marl and clay; and in the States bordering the Mississippi River on the west and in Texas and Arkansas, chalk and clay. Slag and limestone are little used in the United States, although extensively employed in Europe.

In Germany the Alsen and Stettin brands are made from chalk and clay; the Mannheimer and Dyckerhoff brands from limestone and clay; while the Hannover and Germania manufactories use marl and clay.

In England chalk and clay principally are the raw materials.

In Belgium chalk and clay are used by the manufacturers, and a natural rock also is used for the production of a Portland cement.

In France, marl and clay, and chalk and clay, constitute the principal constituents for true Portland cements.

The ordinary composition of a good Portland cement should

approximate the following limits given by H. Le Chatelier, the eminent authority:

	Per Cent
Silica	21 to 24
Alumina	6 to 8
Iron Oxide	2 to 4
Lime	60 to 65
Magnesia	0.5 to 2
Sulphuric Acid	0.5 to 1.5
Carbonic Acid and Water	1 to 3

For a comparison of the chemical composition of the different kinds of cements and of limes, see Table IX, "Typical Analyses of Cements," in Article 157, on the "Classification of Cementing Materials."*

There is a large mass of literature on the subject of "The Constitution of Portland Cement," as it has grown rapidly in importance during recent years.†

176. THE MANUFACTURE OF PORTLAND CEMENTS.—The process of manufacturing Portland cement from rock, or rock and clay mixtures, consists essentially of (a) crushing the materials, either separately or after mixing them, (b) drying, (c) grinding, (d) calcining, (e) cooling, (f) grinding to powder and (g) packing.

There is greater variety in the methods employed for producing Portland cement than for natural cement. Portland cement clinker is not as readily powdered as the burnt natural cement rock, but grinding machinery similar to that used in Portland cement plants is now used in the newer natural cement mills.

The methods of mixing the materials in preparation for their introduction into the kilns has led to a classification of the processes into A, the dry process, and B, the wet process. In these processes either 1, Stationary kilns, or 2, Rotary kilns, are used. The stationary kilns may be either (1) Intermittent kilns, or (2) Continuous kilns.

A.—The dry process was first used in Germany, when limestone

* For a very interesting and complete table giving the analyses of 80 of the most prominent American Portland Cements, see the article on the "Composition of American Portland Cements." Table 221, in "Cements, Limes and Plasters," by Edwin C. Eckel.

† Bonnami, H. Fabrication et contrôle des chaux hydrauliques et des ciments. 8vo. 276 pp. Paris, 1888.

Le Chatelier, H. Tests of hydraulic materials. Trans. Amer. Inst. Mining Engineers, vol 22, pp. 3-52. 1894.

Newberry, S. B. and W. B. The constitution of hydraulic cements. Journ. Soc. Chem. Industry, vol. 16, pp. 887-894. 1897.

Richardson, C. The constitution of Portland cement. *Cement*, vols. 3, 4, 5. 1903-1905.

Richardson, C. The constitution of Portland cement from a physico-chemical standpoint. 12mo, 20 pp. Long Island City, N. Y., 1904.

Richardson, C. The setting or hydration of Portland cement. *Engineering News*, vol. 53, pp. 84-85. Jan. 26, 1905.

was substituted for the chalk of England. In the early days of the industry all cement was burned in stationary kilns. They are still occasionally used in the United States, and to a large extent in Germany and France. They are of two general types, intermittent kilns, which are completely charged and then burned, and continuous kilns, in which there is a continuous maintenance of the fire, and in which the raw materials are dried and heated by the exhaust heat before they are burned.

There has been a universal introduction of rotary kilns into new cement plants, and a gradual substitution of them in the older mills for the stationary kilns. The typical method for the manufacture of Portland cement may be considered to be the dry process with rotary kilns.

In the dry process the ingredients are ground and mixed in a dry state. For stationary kilns the mixed materials are moistened with enough water to make plastic bricks, afterwards dried. For rotary kilns there is no addition of water, and the mixture of dry materials passes, after grinding, directly into the kiln. The following is a brief description of a rotary kiln used for calcining dry materials and of the process of manufacture of the cement from the time of entering the kiln to the packing ready for shipment:*

"The rotary kiln is a steel cylinder, varying in length from 40 to 150 feet and from 4½ to 9 feet in diameter, lined with from 6 to 12 inches of fire-brick, with its axis inclined 8 or 10 degrees to the horizontal, and arranged to rotate at a speed averaging about one turn per minute. The raw materials are introduced at the upper end in form of powder, and in passing through are calcined to a clinker, which leaves the kiln at the lower end in small balls, ranging from ⅛ to 1½ inches in diameter. Finely pulverized gas-slack coal is generally used for fuel, although both gas and oil have been employed, but with poorer results. The coal is blown into the lower end of the kiln, and instantly ignites, forming a flame reaching from 15 to 25 feet into the kiln, and producing a temperature of from 2,600 to 3,000 degrees Fahrenheit. The coal is pulverized in the same manner, and to about the same degree of fineness as the raw materials. The temperature and time of burning vary with the nature of the raw materials.

"The clinker as it leaves the kiln is sprayed with a small stream of water, which cools and makes it more easy to pulverize. It then

* "Concrete, and Reinforced Concrete Construction." Homer A. Reid.

passes through coolers, which reduce it to a normal temperature. From the coolers the clinkers pass to the pulverizing and grinding machines, which are similar to those for reducing the raw material. The finished cement from the grinding machines is conveyed to the stock house, often being stored for a time to give it a chance to 'season' somewhat. It is then packed in bags or barrels for shipment."

B.—The wet process is employed with soft or wet materials, such as chalk and clay, and marl and clay, and may be used with either the stationary or rotary kilns. The latter was first used in England on wet materials. In the United States it is usually only employed by the mills in which the raw material used is marl, although it is adapted to chalk or other materials, which are easily reduced when in a wet condition.

The carbonate of lime and the clay are mixed in a vat or wash-mill with a large excess of water, the lumps are broken up by agitators which reduce the particles to so fine a condition that the water holds them in suspension and they flow off over the top of the vat. The material then settles in another receptacle, the water is drawn off, and the "slurry" becomes hard enough to handle in barrows and then form into bricks to be dried. This is the process for the stationary kilns, in which these bricks are calcined.

Regarding the wet process with rotary kilns, it may be said that these kilns, almost universally adopted in the United States for calcining dry materials, have more recently had their use extended to handling the slurry, of a thick creamy consistency, and drying it with the same flame used for calcination. The wet slurry is pumped into the upper ends of the rotary kilns, which are usually somewhat longer than those employed in the dry process.

After calcination the treatment is similar to that in mills where dry materials are used.

Silica-Portland Cement, or Sand-Portland Cement.—This is a mixture of true Portland cement and siliceous sand ground together into an impalpable powder in a tube-mill.

A mixture of equal parts of sand and cement thus ground together possesses about the same strength as ordinary Portland cement alone.

"A mixture of silica-cement, 1 part cement and 1 part sand, with 3 parts unground sand, has the same composition as 1 part cement

and 7 parts sand; but possessing the strength of a mixture of 1 part cement and 3 parts sand.*

The silica-cement process was first introduced into Denmark and has the special advantage of making mortar that is impermeable to moisture and able to resist the action of the elements.

Eight thousand barrels of silica-cement were used in the foundation of the Cathedral of St. John the Divine, New York City.

177. THE USES OF PORTLAND CEMENTS.—Portland cement is by far the most useful and valuable of all the cements. If quick setting is not necessary, but great ultimate strength required, this cement should be adopted. It is used in almost all kinds of masonry construction, but chiefly in foundations in wet places, in subaqueous work of all kinds, for important structures where great strength is required, and in plain and reinforced concrete work. It is also used in the more exposed parts of ordinary structures, such as the copings of walls and the tops of chimneys, for protecting the outer faces of walls and buildings from the weather, for thin walls where extra strength is required, for pointing and filleting, and for arches, piers and other important parts of buildings and engineering works.

Portland cement, as it has been said elsewhere, has worked a revolution in engineering construction, and is still finding wider and wider fields of application.

In discussing the choice of cements, Messrs. Taylor and Thompson state† that "Portland cement should be used in concrete and mortar for structures subjected to severe or repeated stresses; for structures requiring strength at short periods of time; for concrete building construction; for work laid under water or with which water will come in contact immediately after placing; for thin walls subjected to water pressure; for masonry exposed to wear or to the elements; and for all other purposes where its cost will be less than that of natural cement concrete, or mortar of similar quality."

Mr. Homer A. Reid, in discussing‡ the properties of cement and methods of testing, states that "Portland cement is used for reinforced concrete construction almost to the exclusion of other cements. Its great strength, uniform composition and the regularity of its properties eminently fit it for this class of work."

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*Addison H. Clark, in "Architects' Handbook of Cements."
† "Concrete, Plain and Reinforced." Taylor and Thompson.
‡ "Concrete, and Reinforced Concrete Construction." Homer A. Reid.

Professor C. J. Fiebeger in writing of limes and cement mortars* says, with reference to engineering works in particular, "Portland cement mortar is employed in structures in which great strength is required, as in masonry dams and masonry arched bridges; where the surface is exposed to mechanical wear, attrition, or blows, as in sidewalks and fortifications; and takes the place of natural cement whenever the cost of the work is not thereby increased."

"The cement should be suited to the work in which it is to be used. This will decide whether natural, hydraulic, puzzolan or Portland cement shall be used, and the grade of the latter. Economy should be one of the elements considered and may turn the decision to a natural cement in one locality, while some grade of Portland cement would be used in another. For external work the conditions of variation in temperature, drainage, possibility of shocks, blows and abrasions, and appearance determine the grade of Portland cement to be used."†

178. CHARACTERISTIC PROPERTIES AND REQUIREMENTS OF PORTLAND CEMENT.—

Packages, Field Inspection and Sampling.—The statement made in regard to these particulars under natural cement in Article 165 apply also to Portland cement.

Color.—As was said under this subdivision for natural cement, the color of a cement is no criterion of its quality. It may show, however, too large an amount of some ingredient, and for some particular brand, differences in shade may be an index of variations in the composition of the rock from which the cement was made, or of the degree of burning. "Portland cement should be a dull gray. Bluish-gray probably indicates an excess of lime; dark green, a high percentage of iron; brown, an excess of clay; and a yellowish shade indicates overburning."‡

"The chemical composition of Portland cement made by different processes is so uniform that the color of different brands varies less than that of natural cements.

"The color of Portland cement is described as cold blue gray. The dark color of the coarser particles of a Portland cement left as residue on a screen is due simply to the fact that cement clinker is

* "Civil Engineering." C. J. Fiebeger.
† "Handbook for Cement Users." Charles C. Brown. Published by Municipal Engineering Company, Indianapolis and New York.
‡ "Concrete, and Reinforced Concrete Construction." Homer A. Reid.

black, and pieces which are not finely ground retain the color of the clinker."*

Mr. David B. Butler says† that a brownish color denotes insufficient calcination or the use of unsuitable clay or possibly excess of clay.

The origin of the name "Portland Cement," from a fancied resemblance in its color to the English Portland stone, has already been referred to.

Mr. Austin T. Byrne says‡ that the color of Portland cement should be a dull bluish or greenish gray, caused by the dark ferruginous lime and the intensely green manganese salts; that any variation from its color indicates the presence of some impurity; and that blue indicates an excess of lime, dark green a large percentage of iron, brown an excess of clay and a yellowish shade an underburned material.

Weight.—The quality of a cement is not indicated by the weight alone. If weight is considered it must be taken in conjunction with fineness. Either a fine grinding or an underburning may cause a light weight. Until recently specifications required a standard weight per struck bushel or per cubic foot, the idea being that, other conditions being equal, a cement thoroughly burned is heavier than one underburned. But when it was discovered that the degree of fineness, much more than any difference in calcination, affects the weight, the weight requirements were omitted, and tests for specific gravity substituted.

Experiments have shown that the weight of a cement decreases with age.

According to the specifications of the American Society for Testing Materials, Portland cement should be packed in bags of 94 pounds net weight, four of which make a barrel of 376 pounds net. Some other specifications require a barrel of 375 pounds net. For convenience in ordinary calculations it is often assumed that a barrel of Portland cement weighs 400 pounds gross or 380 pounds net.

In standard proportioning it is assumed to weigh 100 pounds per cubic foot.

Packed in barrels it averages 115 pounds per cubic foot.

Packed Portland cement based on 3.5 cubic feet barrel contents weighs 108½ pounds per cubic foot.

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* "Concrete, Plain and Reinforced." Taylor and Thompson.
† "Portland Cement." David B. Butler.
‡ "Inspector's Pocket Book." Austin T. Byrne.

Loose Portland cement averages about 92 pounds per cubic foot.

Specific Gravity.—Under this heading, in discussing the properties of natural cements, the significance in general of the specific gravity tests for cement was explained.

With Portland cements the specific gravity is of little importance in itself, although it will serve to detect underburned or adulterated cement. A well-dried sample of Portland cement will have a specific gravity which is seldom lower than 3.10, while a natural cement, or a slag cement, or a Portland cement adulterated with slag will have a specific gravity which is rarely higher than 3.00. It must be admitted, however, that there are a few American natural cements showing a specific gravity of 3.00, and reaching as high as 3.2.

The standard specifications of the American Society for Testing Materials require that the specific gravity of Portland cement, thoroughly dried at 100° Cent. (212° Fahr.), shall be not less than 3.10.

Mr. Homer A. Reid says* "the specific gravity of Portland cement varies from 3.00 to 3.25, but for the higher grades of American cements it is usually found to be between 3.10 and 3.25."

Activity, or Time of Setting.—A brief general description of the use and significance of the tests for this property has already been given under natural cements.

The specifications of the American Society for Testing Materials require that Portland cement shall develop "initial set" in not less than thirty minutes, but must develop "hard set" in not less than one hour nor in not more than ten hours.

Portland cements are generally much slower in setting than natural cements. There are, however, as was mentioned under natural cements, a few of the latter which are slow-setting.

Soundness, or Constancy of Volume.—The purpose and general description of the test was described under natural cements, and those phenomena common to both natural and Portland cements were mentioned.

The soundness tests are of greater importance than any other, and are often the only ones necessary. An unsound cement is likely to go to pieces on the work.

The following are the requirements in the specifications of the American Society for Testing Materials for Soundness or Constancy of Volume of Portland Cement:

Pats of neat cement about three inches in diameter, one-half inch

* "Concrete and Reinforced Concrete Construction." Homer A. Reid.

thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(a) A pat is then kept in air at normal temperature, and observed at intervals for at least 28 days.

(b) Another pat is kept in water maintained as near 70° Fahr. as practicable, and observed at intervals for at least 28 days.

(c) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

These pats to satisfactorily pass the requirements shall remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

Engineers are pretty well agreed that it is safe to adopt the following conclusion: "If a Portland cement passes the hot test it may be used immediately with reasonable certainty of its ultimate soundness. If it fails to pass, it should be regarded with suspicion and thoroughly tested."

The following are useful and simple directions for soundness testing for small purchasers of Portland cement: "Take about ½ pound, or one cupful, of Portland cement and mix by kneading 1½ minutes with sufficient water to form a paste of a consistency like putty. Press portions of the paste onto 3 pieces of window glass 4 inches square, so as to make 3 pats each about 3 inches in diameter and ½ an inch thick at center, tapering to a thin edge, and place in moist air for 24 hours. Then keep one pat in air at moderate temperature (about 60° or 70° Fahr.) for 28 days, keep second pat in water for 28 days, and place third pat in loosely closed vessel over boiling water and keep there for five hours. Reject cement if any pats show radial cracks or curl or crumble. The air pat should not change color. Portland cement may be accepted on the steam test alone if time is limited. Natural cements should be subjected to water and air but not to steam."*

Fineness.—The general significance of the fineness tests for all cements was explained under this subdivision in treating of natural cements.

The following are the requirements for the fineness of a Portland cement, taken from the standard specifications of the American Society for Testing Materials "It shall have by weight a residue of

* "Concrete, Plain and Reinforced." Taylor and Thompson.

not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve."

The fineness requirements of some other specifications for Portland cement used in important works are as follows:

(1) Rapid Transit Subway, New York City, 1900-1901:

"Ninety-eight per cent shall pass a No. 50 sieve and 90 per cent a No. 100 sieve."

(2) New York State Canals, 1896:

"Portland cement must be of such fineness that 95 per cent of the cement will pass through a sieve of 2,500 meshes to the square inch, and 90 per cent through a sieve of 10,000 meshes per square inch."

(3) Department of Bridges, New York City, 1901:

"Cement must be ground so fine that 90 per cent of it will pass through a sieve of 10,000 meshes per square inch."

(4) Engineer Corps, U. S. Army, 1902:

"Ninety-two per cent of the cement must pass through a sieve made of No. 40 wire, Stubbs' gauge, having 10,000 openings per square inch."

(5) U. S. Reclamation Service, 1904:

"Ninety-five per cent by weight must pass through a No. 100 sieve having 10,000 meshes per square inch, the wire to be No. 40 Stubbs' wire gauge; and 75 per cent by weight must pass through a No. 200 sieve having 40,000 meshes per square inch, the wire to be No. 48 Stubbs' wire gauge."

(6) Canadian Society of Civil Engineers, 1903:

"The cement shall be ground so fine that the residue on a sieve of 10,000 meshes to the square inch shall not exceed 10 per cent of the whole by weight, and the whole of the cement shall pass a sieve of 2,500 meshes to the square inch."

The following is a simple test for the fineness of a cement: "Sift 5 ounces of dry cement containing no lumps through a sieve about 6 to 8 inches diameter with 100 meshes per linear inch. Not more than ½ ounce of either Portland or natural cement should remain on sieve. To compare quality of two brands otherwise similar, sift through a 200-mesh sieve and choose the finer cement."*

179. STRENGTH TESTS FOR PORTLAND CEMENTS.—

* "Concrete, Plain and Reinforced." Taylor and Thompson.

As was stated under this subdivision of natural cements, a brief description of the manner of applying strength tests to cement is given in division 6, of this chapter, entitled "Strength Tests for Cements." A standard requirement, however, will be given here.

The requirements for tensile strength of Portland cement, as given in the specifications of the American Society for Testing Materials, 1904, are as follows:

"The minimum requirements for tensile strength for briquettes one inch square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

Age.	Strength.
NEAT CEMENT.	
24 hours in moist air	150-200 pounds.
7 days (1 day in air, 6 days in water)	450-550 pounds.
28 days (1 day in air, 27 days in water)	550-650 pounds.
ONE PART CEMENT, THREE PARTS SAND.	
7 days (1 day in air, 6 days in water)	150-200 pounds.
28 days (1 day in air, 27 days in water)	200-400 pounds."

The tensile test is the one most commonly applied strength test, because it is difficult to make an accurate compressive test. The ratio between compressive and tensile strength is quite uniform, and is about 10.

For a list of other "Strength Tests of Cements and Cement Mortars," and a list of the "Special Tests of Cements and Mortars" see Articles 166 and 167 under the subject "Natural Cements."

180. SPECIFICATIONS FOR PORTLAND CEMENTS.—As was stated under this heading for natural cements, the specifications for the cement for any operation are based upon the result of tests, upon experience and practice, and upon the study of model requirements for the most recent and approved modern works.

The set of specifications given under natural cements and the following set here are sufficient to indicate the general form, the details of the requirements, of course, differing for Portland cement. It is not possible here to give the different specifications for the latter, and the reader is referred to various treatises on cements, and to the bibliographies of cement specifications published here and elsewhere.

One most excellent set is given, however, the specifications for Portland cement, based upon the practice of Engineers F. W. Taylor and S. E. Thompson, supplemented by a careful study of the specifications of the following: American Society for Testing Ma-

terials, American Railway Engineering and Maintenance-of-Way Association, City of Philadelphia, United States Army, United States Navy, Massachusetts Metropolitan Commissions, New York Rapid Transit Commission, and others.

1. *Packages.*—Cement shall be packed in strong cloth or canvas sacks.† Each package shall have printed upon it the brand and name of the manufacturer. Packages received in broken or damaged condition may be rejected or accepted as fractional packages.

2. *Weight.*—Four bags shall constitute a barrel, and the average net weight of the cement contained in one bag shall be not less than 94 pounds or 376 pounds net per barrel. A cement bag may be assumed to weigh one pound. The weights of the separate packages shall be uniform.

3. *Requirements.**—Cement failing to meet the seven-day requirements may be held awaiting the results of the twenty-eight-day tests before rejection.

4. *Tests.**—All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the society January 21, 1903, and amended January 20, 1904, with all subsequent amendments thereto.

5. *Sampling.*—Samples shall be taken at random from sound packages, and the cement from each package shall be tested separately.

6.* The acceptance or rejection shall be based on the following requirements:

7. *Definition of Portland Cement.**—This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous‡ and calcareous§ materials, and to which no addition greater than 3 per cent has been made subsequent to calcination.

8. *Specific Gravity.**—The specific gravity of the cement, thoroughly dried at 100° Cent. (212° Fahr.), shall be not less than 3.10.

9. *Fineness.**—It shall leave by weight a residue of not more

*Paragraphs designated by an asterisk are quoted from the Standard Specifications of the American Society for Testing Materials.

†If the cement is to be stored in a damp place or near the sea, it must be packed in well-made wooden barrels lined with paper.

If stored in a dry place to be used immediately, it may be packed in stout cloth or canvas bags which are of course cheaper than barrels.

‡Clayey.

§ Consisting chiefly of lime or calcium.

than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

10. *Time of Setting.**—It shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour nor more than ten hours.

11. *Tensile Strength.*†—Briquettes one inch square in section shall attain at least the following tensile strengths and shall show no retrogression within the periods specified:

NEAT CEMENT.

Age.	Strength.†
24 hours in moist air	175 lbs.
7 days (1 day in air, 6 days in water)	500 lbs.
28 days (1 day in air, 27 days in water)	600 lbs.

ONE PART CEMENT, THREE PARTS STANDARD SAND.

Age.	Strength.†
7 days (1 day in moist air, 6 days in water)	150 lbs.
28 days (1 day in moist air, 27 days in water)	200 lbs.

12. *Soundness or Constancy of Volume.**—Pats of neat cement about three inches in diameter, one-half inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature, and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70 degrees Fahr. as practicable, and observed at intervals for at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

These pats to satisfactorily pass the requirements shall remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

13. *Sulphuric Acid and Magnesia.*—The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of Magnesia (MgO).

In writing on "Specifications for Portland Cement," Mr. Edwin

*Paragraphs designated by an asterisk are quoted from the Standard Specifications of the American Society for Testing Materials.

†The American Society for Testing Materials gives minimum requirements as follows: Neat Cement—24 hours, 150-200 lb.; 7 days, 450-550 lb.; 28 days, 550-650 lb. 1:3 mortar—7 days, 150-200 lb.; 28 days, 200-300 lb.; the exact values to be fixed in each case by the consumer.

C. Eckel* has collected and published various specifications, and states that they are of interest partly for comparison and partly to show the growth of intelligent treatment of the subject. He also states that the specifications of the American Society for Testing Materials will probably become the standard in this country.

181. MISCELLANEOUS DATA AND MEMORANDA ON PORTLAND CEMENTS.—Reference should here be made to the corresponding Article, 169, under Natural Cements, as occasional data these are for Portland Cements.

The following are some useful notes compiled† to show the weights and measurements of contents of a barrel of Portland cement. (See also Article 178.)

A barrel of Portland cement weighs about 380 pounds net.

A barrel of Portland cement weighs about 400 pounds gross.

A barrel of Portland cement contains about 3.40 cubic feet packed.

A barrel of Portland cement contains about 4.25 cubic feet loose.

A barrel of Portland cement contains about 2.73 bushels packed.

A barrel of Portland cement contains about 3.61 bushels loose.

182. THE CHOICE OF PORTLAND CEMENTS, AND THE SELECTION OF BRANDS.—The reader is here referred to Article 170, under Natural Cements, which considered the question of deciding between the two classes of cements in any case, and also the question of the selection of some particular brand of either.

5. PUZZOLAN CEMENTS.

183. CLASSIFICATION.—The puzzolan cements belong to the silicate division of the complex cementing materials. They differ from the other three classes of the silicate cements, the hydraulic limes, natural cements and Portland cements, as their raw materials are not calcined after mixture.

184. DEFINITION OF PUZZOLAN CEMENT.—Puzzolan cement is a mechanical mixture of certain natural or artificial

* "Cements, Limes and Plasters." Edwin C. Eckel.
The following is the list of these specifications:
1. New York State Canals. 1896.
2. Rapid Transit Subway, New York City. 1900-1901.
3. Department of Bridges, New York City. 1901.
4. Engineer Corps. U. S. Army. 1902.
5. U. S. Reclamation Service. 1904.
6. Canadian Society of Civil Engineers. 1903.
7. Concrete-Steel Engineering Company. 1903.
8. British Standard Specifications. 1905.
9. American Society for Testing Materials. 1904.

† "Handbook for Superintendents of Construction." H. G. Richey.

products, such as volcanic ash or blast-furnace slag, with powdered slaked lime. The term *puzzolan* has been adopted by many authorities and is now in general use. The material was first obtained near the town of Pozzuoli, a few miles west of Naples, from which place the Italian *pozzuolana* takes its name.

185. THE CHEMICAL ANALYSIS OF PUZZOLAN CEMENTS.—In Article 157 on the "Classification of Cementing Materials," in Table IX, "Typical Analyses of Cements," the average chemical analysis is given. The puzzolanic materials in composition are made up largely of silica and alumina, and usually with more or less iron oxide; and some of these materials, such as the slags used in cement-manufacture, contain in addition notable percentages of lime.

186. THE MANUFACTURE OF PUZZOLAN CEMENTS.—Puzzolanic materials include the (1) natural and (2) the artificial materials. To the first class belong the direct products of volcanic action, and to the second class the blast-furnace slag and some other artificial materials, such as burnt clay.

In using the natural materials, they are dug out from the deposits, screened and ground and occasionally slightly roasted to increase their hydraulic properties.

In using the artificial materials, as blast-furnace slag, no kilns are used, and the molten slag coming from the furnace is chilled and granulated by a stream of cold water, and separated from most of its sulphur. It is then dried and may or may not have a preliminary grinding before the addition of the slaked lime.

The production of puzzolan cement in the United States in 1906 was 481,224 barrels, valued at $412,921.

An advantage of this industry lies in the fact that it utilizes and consumes a product of steel and iron foundries which has for years been troublesome to dispose of and regarded as a waste product.

187. THE USES OF PUZZOLAN CEMENTS.—The following are the generally accepted conclusions regarding the proper uses of puzzolan cement:

(1) It never becomes extremely hard, like Portland cement.

(2) Puzzolan mortars are tougher or less brittle than Portland cements.

(3) It is well adapted for use in sea-water.

(4) It is well adapted for use in all positions constantly exposed to moisture.

(5) It is suitable for use in foundations of buildings in damp places.

(6) It may be used in sewers, drains and in underground works generally.

(7) It may be used in the interior of heavy masses of masonry or concrete.

(8) It is not suitable for use in any positions subjected to mechanical wear, attrition or blows, and it should not be employed in places where it is liable to be exposed for long periods to dry air, even after it has reached its hardest set.

(9) It has a tendency to change to a whitish color and to disintegrate, on account of the oxidation of its sulphides at and near the surface, when exposed to dry air as mentioned in (8).

188. CHARACTERISTICS AND PROPERTIES OF PUZZOLAN CEMENTS.—*Color.*—Puzzolan cement made from slag can usually be distinguished from Portland cement by its decidedly lighter color and slightly different tint, and from natural cements by a marked difference in tint. The color varies from bluish-white to lilac. This cement is also characterized by the intense bluish-green color in the fresh fracture after long submersion in water, due to the presence of sulphides, which color fades after exposure to dry air. Slag cements do not stain masonry.

Weight.—Slag cement weighs about 350 pounds gross, or 330 pounds net, per barrel.

Specific Gravity.—The slag cements are lighter than the Portland cements, and for the same weight more bulk is obtained. The usual range of variation in the specific gravity of the slag cements is from 2.7 to 2.9, as compared with the fair average 3.15 for good Portland cement.

Activity or Time of Setting.—Slag cements are generally slower setting than Portland cements. The use to which the cement is put determines whether or not slow set is desirable. Rapidity of set varies decidedly with the amount of alumina in the slag. Burned clay, active forms of silica, slags high in alumina, etc., when added hasten the set. Alkalies accelerate the set.

Soundness or Constancy of Volume.—To test the soundness, pats of neat cement mixed for five minutes with 18 per cent of water by weight are made on glass, each pat about 3 inches in diameter and ½ an inch thick at the center, tapering thence to a thin edge. They are kept under wet cloths until finally set, when they are placed in

fresh water. They should not show distortion or cracks at the end of twenty-eight days.

Fineness.—Ninety-seven per cent of the puzzolan or slag cement should pass through a sieve made of No. 40 wire, Stubbs' gauge, having 10,000 openings per square inch.

189. STRENGTH OF PUZZOLAN OR SLAG CEMENTS.—Slag cements approximate in tensile strength similar mixture of Portland cements. In compressive strength, however, their resistance is less, the ratio of compressive to tensile strength being about from 5 to 7 to 1 for slag cements, and from 9 to 11 to 1 for Portland cements. Slag cements also often give nearly as great tensile strength in 3 to 1 mixtures as in neat briquettes, this being due to the fact that they are ground very fine.

190. SPECIFICATIONS FOR PUZZOLAN CEMENTS.—Detailed specifications for puzzolan cements have been prepared and published by the Engineer Corps, U. S. Army, and are to be found in most of the treatises on limes, cements, mortars and concretes.*

6. STRENGTH TESTS FOR CEMENTS.

191. STRENGTH TESTS IN GENERAL.—The object of strength tests for cement mortars is to determine their strength in actual work. As it is easier to make the test for tension than for compression, shear, flexure, adhesion, etc., and as the tensile strength bears a generally constant relation to these other stresses, it is the tension test that is usually made. The tests are made on neat cement and on cement mixed with varying proportions of sand. The former indicate the character and quality of the material, the latter the strength under actual conditions. (See also Articles 166 and 208.)

For Portland cement, sand mixture tests, 1 part by weight of cement to 3 parts of sand are used; and for natural and slag cements, 1 to 1 and 1 to 2. The briquettes are broken at periods of 24 hours, 7 days, and 28 days for neat tests, longer periods being necessary for special experimental purposes.

192. NORMAL CONSISTENCY OF MORTAR.—This means the use of a proper percentage of water in making the pastes for the pats, briquettes, etc. Various methods are followed for making this determination. A simple method is to mix the cement

* Among other books in which these specifications are published is "Cements, Limes and Plasters," by Edwin C. Eckel.

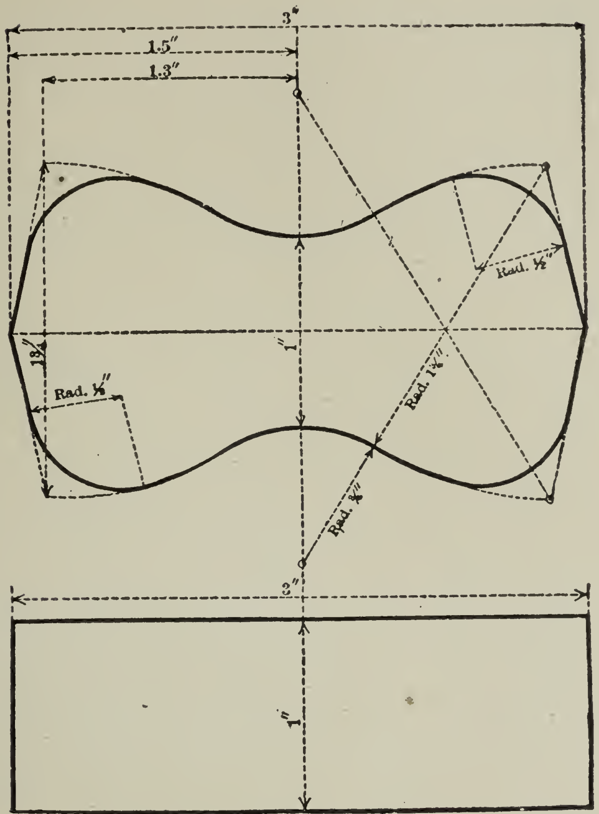


Fig. 89. Standard American Form of Cement Briquette.

paste to such a degree of plasticity that when a ball of the paste 2 inches in diameter is dropped upon a hard surface from a height of 2 feet it will not crack or flatten more than half its original thickness.

193. FORM OF BRIQUETTE.—The standard American form of briquettes, with which the tensional tests are usually made, is shown in Fig. 89. This is the form adopted by the Special Committee on Uniform Tests of Cement of the American Society of Civil Engineers. The minimum cross-sectional area is one square inch. The molds are made of brass, and are either single or in gangs of three or four, as shown in Fig. 90. In making the tests a solid metal clip of the form shown in Fig. 91 is used without cushioning at the points of contact. The bearing is ¼ of an inch

wide, and the distance between centers of contact on same clip should be $1\frac{1}{4}$ inches.

194. METHOD OF MIXING.—A careful determination by weight of the proportions of cement, sand and water is made, the sand and cement mixed dry, and the water added all at once. A rapid and thorough mixing of the mortar then follows, and when it is stiff and plastic it is pressed firmly into the molds with a trowel, without ramming, and struck off level. The mixing is done upon a glass or slate slab, the hands being protected by rubber gloves.

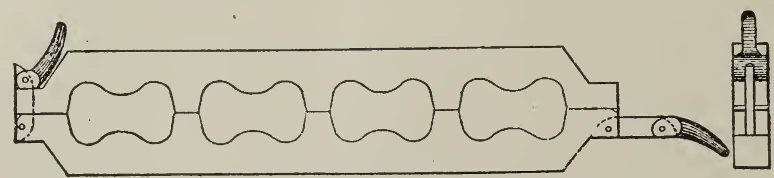
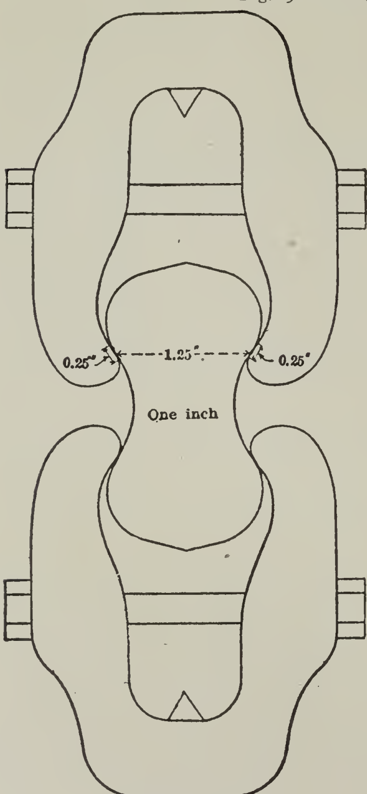


Fig. 90. Gang-Mold for Cement Briquettes.

195. STORING THE BRIQUETTES OR TEST PIECES. During the first 24 hours after molding, the test pieces are stored in a damp atmosphere to prevent them from drying out. They are then immersed in water until tested.

196. TESTING MACHINES.—There are many testing machines in use, all of them rather expensive. When properly used, any one of them will give satisfactory results. These machines and their detailed operation are discussed and illustrated in the treatises on these subjects.

A home-made testing machine of low cost is shown in Fig. 92. It can be made by an ordinary mechanic at small expense. It is not as convenient nor quite as



FORM OF CLIP.

Fig. 91. Standard Metal Clip for Testing Cement Briquettes.

accurate as the more elaborate machines, but it is sufficiently accurate for all practical purposes. "The machine consists essentially of a counterpoised wooden lever, 10 feet long, working on a horizontal pin, between two broad uprights, 20 inches from one end. Along the top of the long arm runs a grooved wheel carrying a weight, *W′*. The distances from the fulcrum in feet and inches are marked on the surface of the lever, and also the corresponding effect of the weight at each point. The clamp for holding the briquette is suspended from the short arm, 18 inches from the fulcrum. The clamps are of wood and are fastened by clevis points to the lever arm and bed-plate respectively. The pin is iron and the pin holes are reinforced by iron washers. When great stresses are required extra weights are hung on the end of the long arm. Pressures of 3,000 pounds have been developed with this machine."

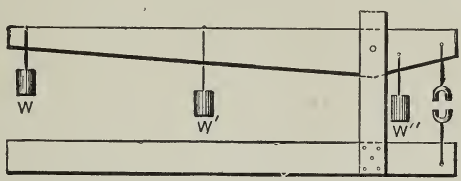


Fig. 92. Simple Machine for Approximate Cement Tests.

In applying the load on the briquette it is recommended that it start at 0 and be increased regularly at the rate of 400 pounds per minute for neat Portland cements, and 200 pounds per minute for natural cements and mortar.

A rough test may be made by suspending the clamps from a beam or trestle and hanging a bucket or box from the lower clamp, into which sand is run until the briquette breaks, when the sand is weighed.

197. TENSILE STRENGTH OF CEMENT MORTARS.—Tests of tensile strength are made to determine the strength which will develop in a certain time, and the ultimate strength. A cement should never decrease in strength. The usual stipulations are that the materials must pass a minimum strength acquirement at 7 and 28 days.

The sand test is the true criterion of strength, and there should be no acceptance of any cement failing to satisfactorily pass it, even though the neat tests have not failed.

Cement and cement mixtures attain a strength not differing greatly from the ultimate strength within a period of three months

from the time of setting, and practically within a month or so after this period no appreciable change of strength takes place.*

The following table† gives the approximate values for the tensile strength of first-class Portland, natural and slag cements in neat and sand tests:

TABLE XIV.

Tensile Strengths of Portland, Natural and Slag Cements.

PORTLAND CEMENT.

Age.	Neat.	Strength.
24 hours (in moist air)		175 lbs.
7 days (1 day in moist air, 6 days in water)		500 lbs.
28 days (1 day in moist air, 27 days in water)		600 lbs.

Age.	One Part Cement, Three Parts Sand.	Strength.
7 days (1 day in moist air, 6 days in water)		170 lbs.
28 days (1 day in moist air, 27 days in water)		240 lbs.

NATURAL CEMENT.

Age	Neat.	Strength.
24 hours (in moist air)		40 lbs.
7 days (1 day in moist air, 6 days in water)		125 lbs.
28 days (1 day in moist air, 27 days in water)		225 lbs.

Age	One Part Cement, Two Parts Sand.	Strength.
7 days (1 day in moist air, 6 days in water)		75 lbs.
28 days (1 day in moist air, 27 days in water)		140 lbs.

SLAG CEMENT.

Age	Neat.	Strength.
7 days (1 day in moist air, 6 days in water)		350 lbs.
28 days (1 day in moist air, 27 days in water)		500 lbs.

Age.	One Part Cement, Three Parts Sand.	Strength.
7 days (1 day in moist air, 6 days in water)		140 lbs.
28 days (1 day in moist air, 27 days in water)		220 lbs.

198. COMPRESSIVE STRENGTH OF CEMENT MORTARS.—Compression tests of cement are not generally made in the United States, although they are made in Europe. When they are made the ends of the specimens broken in tension are often used in making the test. The ratio of the compressive to the tensile strength, in natural cements and slag cements, seems to be lower than in Portland cements, in which latter it may be taken as 10. For natural cement the average ratio is 4.9, and for slag cements 5.3, as determined by a series of tests. See also Article 208,

* See "Cements, Mortars and Concrete." Myron S. Falk.

† "Concrete and Reinforced Concrete Construction." Homer A. Reid.

"Strength of Mortar," and Article 189, "Strength of Puzzolan or Slag Cements."

199. OTHER STRENGTH PROPERTIES.—*Transverse or Flexure Tests* have been made on beams and prisms of cement mortars, but are now seldom used. Their principal value is in comparing the direct tensional stress with the tensile fiber stress due to flexure.

A relation has been determined between the ultimate tensile and *flexural fiber stresses* of cement mortar briquettes, and the tensile flexural fiber stress has been found from several series of careful experiments to be 1.9 times the simple direct tensile stress of the same material.*

Tests have been made to determine the *adhesive strength* of cement mortars. There is a great variation in the adhesive strength of mortars made from different cements.

The *adhesion* of mortar to a stone or brick surface depends upon the state of the surface and the nature of the cement used. It is less than the tensile strength of the mortar.† The adhesion increases as the surface receiving the mortar becomes more porous. Irregularities of the surface of stone do not seem to affect the adhesive strength, but with iron, roughening the surface increases the adhesion of the mortar. A dirty surface or insufficient moistening of the surface lowers the adhesion. The average ultimate adhesive strength of cement mortar to brick surfaces may be taken at from 25 to 85 pounds per square inch.

In the use of iron or steel for reinforcement, and the setting of bolts in mortar and concrete, the whole question of the adhesion of mortar to iron or steel is one of great importance, but belongs to discussions in connection with reinforced concrete. From 200 to 500 pounds per square inch may be taken as average figures for the ultimate adhesive strength of cement mortar to iron rods or bolts imbedded in it.

See also in Article 209, "The Adhesion of Mortars."

Shearing tests have been made upon different mortars, and the shearing resistances for Portland cement mortars found to be very much less than the compressive resistance.‡

* M. Durand-Claye in "Commission des Méthodes d'Essai des Matériaux de Construction," 1895, Vol. IV, p. 211.
† "Mechanics of Materials." Mansfield Merriman.
‡ For a comparison of Flexural, Tensional, Compressive and Shearing Strength of Portland Cement Mortars, see very comprehensive tables in Chapter IX of "Concrete, Plain and Reinforced," by Taylor and Thompson.

The *coefficient of elasticity* of American natural cements has been found to vary from 500,000 to 1,800,000 pounds per square inch, and of American Portland cements from 2,300,000 to 4,500,000 pounds per square inch.

7. CEMENT MORTARS.

200. USE.—Cement mortar should be used for all mason work which is below grade, or situated in damp places, and also for heavily loaded piers and arches of large span. It should be used for setting coping stones, and wherever the mason work is especially exposed to the weather.

For construction under water, and in heavy stone piers or arches, and for concrete, Portland cement should be used; elsewhere natural cement mortar will answer.

See also the articles relating to the "Uses" of the various cements.

201. MIXING THE MORTAR.—The following are directions for hand mixing cement mortar for ordinary masonry: Spread about half the sand required for mixing evenly over the bed of the mortar box (which should be water-tight), and then spread the dry cement evenly over the sand and spread the remaining sand on top. Thoroughly mix the dry sand and cement with a hoe or shovel, as this is a very essential part of the process. Shovel the dry mixture to one end of the box and pour water into the other end. ("Cements vary greatly in their capacity for water, freshly-ground cements requiring more than those that have become stale. An excess of water is, however, better than a deficiency, particularly when a very energetic cement is used, as the capacity of this substance for absorbing water is great.") Draw down with a hoe the sand and cement in small quantities and mix with the water until enough has been added to make a good *stiff* mortar, taking care not to get it too thin. Work the mortar vigorously with a hoe for five minutes to get a thorough mixture.

The mortar should leave the hoe clean when drawn out of it, very little sticking to the steel. But a very small quantity of cement mortar should be mixed at a time, particularly that made of natural cements, as mortars made from these cements soon commence to set, after which they should not be used. As a rule natural cement mortars should not be used after they have been mixed two hours, and Portland cement mortars after four hours (for best work not over one hour).

The sand and cement should not be mixed so as to stand over night, as the moisture in the sand will destroy the setting qualities of the cement.

Mechanical mixtures are frequently used in large operations, with a lessening of the labor of manipulating the materials, and, when employed with great care, with a uniformity of good work. The principal objection to these mixers is the failure to thoroughly intermix the dry cement and sand, and the temptation to lighten the labor of the wet mixing by giving an overdose of water.

202. KEEPING CEMENT MORTARS MOIST.—"Hydraulic cements set better and attain a greater strength under water than in the open air; in the latter, owing to the evaporation of the water, the mortar has a tendency to dry rather than to set. This difference is very marked in hot, dry weather. If cement mortar is to be exposed to the air it should be shielded from the direct rays of the sun and kept moist."

203. PROPORTION OF SAND.—"A paste of good hydraulic cement hardens simultaneously and uniformly throughout the mass, and its strength is impaired by any addition of sand." As mortar is never used by itself, however, but as a binding material for brick and stone, and there can obviously be no advantage in making the strength of the mortar joints greater than that of the bricks or stones they unite, sand is always added to the cement in making mortar. Sand also generally reduces the tendencies to shrink and crack, especially in lime mortar. As cement is much more expensive than sand, the larger the proportion of sand in the mortar the less will be its cost. The proportion of sand should vary according to the kind of cement and the kind of work for which the mortar is to be used. For natural cements the proportion of sand to cement by measurement should not exceed 3 to 1, and for piers and first-class work 2 to 1 should be used. Portland cement mortar may contain 4 parts of sand to 1 of cement for ordinary mortar, and 3 to 1 for first-class mortar. For work under water not more than 2 parts of sand to 1 of cement should be used. When cheaper mortars than these are desired it will be better to add lime to the mortar instead of more sand.

The following are the proportions of cement and sand generally used for some specific purposes:

For masonry and brickwork, 1 part cement to 2, 3, or 4 parts of sand, according to strength required and purposes for which the

mortar is to be used. For some special purposes 5, or even 6, parts of sand have been used.

For face brickwork, 1 part cement to 2 parts of sand.

For backing and in ordinary masonry foundations, 1 part cement to 3 parts of sand.

For brick piers and first-class brickwork, not more than 2 parts of sand to 1 of natural cement should be used, and 1 or 1½ parts of sand will make a still stronger mortar.

For cement plastering, equal parts of natural cement and sand.

For rubble stonework under ordinary conditions, 1 part Portland cement to 4 parts of sand are frequently used and found to satisfy every condition.

For top surfaces of floors and walks, 1 part Portland cement to from 1 to 1½ parts of sand.

The superintendent should see that the cement and sand for each batch of mortar are carefully measured to get the right proportions.

To mortars composed of the same cement with different proportions and sizes of sand two fundamental laws* of strength may be applied.

The first law is that with the same aggregate—that is, the inert material, such as sand, broken stone, etc., with which the cement or other adhesive material is mixed to form mortar or concrete—the strongest and most impermeable mortar is that containing the largest percentage of cement in a given volume of the mortar.

The second law is that with the same percentage of cement in a given volume of mortar, the strongest, and usually the most impermeable, mortar is that which has the greatest density; that is, the mortar which in a unit volume has the largest percentage of solid materials.

Plastering mortar, for stucco work or waterproofing, should be made of 1 part cement and 1 part sand. For lining cisterns 2 parts of natural cement or 1 of Portland cement should be used.

The following table† shows the comparative strength of English Portland cement mortar, with different proportions of sand and at different ages:

* "Concrete, Plain and Reinforced." Chapter IX. Taylor and Thompson.

† This table shows the comparative ultimate tensile strengths of some English neat cements and sand mixtures. The reader is referred to the numerous and detailed reports of recent tests made on American cement mortars of all kinds, and printed in various bulletins and treatises on these subjects.

TABLE XV.

STRENGTH OF ENGLISH PORTLAND CEMENT MIXTURES.

AGE AND TIME IMMERSED.	PROPORTION OF CLEAN PIT SAND TO 1 CEMENT.					
	Neat cement.	1 to 1.	2 to 1.	3 to 1.	4 to 1.	5 to 1.
One week	445.0	152.0	64.5	44.5	22.0	.....
One month	679.9	326.5	166.5	91.5	71.5	49.0
Three months	877.9	549.6	451.9	305.3	153.0	123.5
Six months	978.7	639.2	497.9	304.0	275.6	218.8
Nine months	995.9	718.7	594.4	383.6	.....	.....
Twelve months	1,075.7	795.9	607.5	424.4	317.6	215.6

P. 177, "Notes on Building Construction," Part III.

The values in the table represent the breaking strength in pounds on a sectional area of 2¼ square inches.

See also the various tables and specifications given in other articles of this chapter, showing the decrease in strength due to larger proportions of sand.

204. PORTLAND AND ROSENDALE CEMENT, MIXED. —"Mixtures of Portland and natural cements, unless mixed at the factory and sold as Improved Natural Hydraulic Cements, are not advised under any conditions."*

205. CEMENT-LIME MORTARS.—Some constructions require quick-setting mortars, but do not need the strength nor warrant the expense of a 1 to 2, 3 or 4 mixture of cement and sand. A 1 to 5 or more mixture would give ample strength, but would work "short"; that is, it would not work easily, rapidly and smoothly on the trowel. It would not adhere perfectly to the stone or brick, and could not be safely used. The addition of a limited quantity of slaked or hydraulic lime corrects these faults, results in a cheaper mortar, and gives a mixture suited to a great variety of uses. It permits the use of Portland cement mortar for very many purposes.

The following are the principal advantages of Portland cement-lime mortar:

(1) Cheapness in comparison with other hydraulic materials.
(2) Rapidity of setting and hardening.
(3) Marked hydraulic properties.

*See Taylor and Thompson in "Concrete, Plain and Reinforced," in the discussions on "The Choice of Cement" and "The Class of Cement."

(4) Great strength on exposure to air.

(5) Remarkable resistance to the weather.

In making cement-lime mortar the sand and cement are thoroughly mixed dry, the lime putty is mixed with water and screened into a mortar box, and the whole is then thoroughly mixed and worked together until a proper consistency is obtained.

The following are mixtures by measure that have been used with excellent results:

Cement 1 part, sand 5 parts, lime paste ½ part.
Cement 1 part, sand 6 to 7 parts, lime paste, 1 part.
Cement 1 part, sand 8 parts, lime paste 1½ parts.
Cement 1 part, sand 10 parts, lime paste 2 parts.

In regard to the strength, a mixture of Portland cement 1, lime paste 1, sand 6, is as good as a mixture of Portland cement 1, sand 3, in this case one-half the cement being replaced without loss of strength.

Portland cement-lime mortar is very much stronger, and little or no more expensive than natural cement-lime mortar.

206. GROUT.—This is a very thin liquid mortar sometimes poured over courses of masonry or brickwork in order that it may penetrate into empty joints left in consequence of bad workmanship. It is also sometimes necessary to use it in deep and narrow joints between large stones. The mortar may be neat or have various proportions of sand added, say from ½ to 2 parts to one part of cement. Its use is not generally recommended by writers on mortars, and the author believes that it should not be used in stonework where it can be avoided. For brickwork, however, the author feels convinced that walls grouted with a moderately thin mortar every course makes a solid job. If the bricks are well wet before laying, and every joint slushed full of stiff mortar, it is impossible to get anything stronger; but in most localities it is difficult to get such work without keeping an inspector constantly on the ground, and when the walls are grouted the joints are sure to be filled. In his own practice the author always specifies grouting for all brick footings and foundation walls. Many of the largest buildings in New York City have grouted walls.

"Grouting is not now considered a first-class method of construction. It has, however, been used successfully in many cases, and will at times prove useful when, on account of local conditions,

other methods cannot be used. It has been successfully used for subaqueous foundation work by English engineers, both in India and Europe."*

The usual method of mixing is as follows: The cement is mixed, on a flat platform or ordinary mixing board, to the consistency of stiff paste, and then placed in a tub and slightly thinned down by the addition of water in small quantities. It is then stirred until the paste is reduced to a thick grout, just soft enough to leave the bucket. It is poured rapidly; the faster the pouring and the more continuous the flow the better the results obtained. (See Chapter VII, Article 342, "Grouting Brick Walls.")

207. DATA FOR ESTIMATES.—The following memoranda, made up from data given by Prof. Ira O. Baker, will be found useful in estimating the amounts of materials required in making any given quantity of mortar:

Lime Mortar.—The weight of a barrel of lime is often taken at about 230 pounds net; a bushel of lime at 75 pounds. At these weights one barrel (or three bushels) of lime and 1 yard of sand will make 1 yard of 1 to 3 lime mortar, and will lay about 80 cubic feet of rough brickwork or common rubble.

The following data are given by Mr. H. G. Richey:

"1 barrel of lime will make 2¾ barrels of paste.
1 barrel of lime will lay 3 perches of stone rubble.
1 barrel of lime will lay 1,000 to 1,200 bricks.
1 barrel of lime will plaster 28 yards of 3-coat work.
1 barrel of lime will plaster 40 yards of 2-coat work.
1 barrel of lime equals 3 bushels of 80 pounds each."†

Cement Mortar.—1.8 barrels, or 540 pounds, of natural cement and .94 cubic yard of sand will make 1 cubic yard of 1 to 3 mortar; two barrels, or 675 pounds, of Portland cement and .94 cubic yard of sand will also make 1 cubic yard of 1 to 3 mortar; 1.7 barrels, or 525 pounds, of Portland cement and .98 cubic yard of sand will make 1 cubic yard of 1 to 4 mortar; 1 cubic yard of mortar will lay from 67 to 80 cubic feet of rough rubble or brickwork, from 90 to 108 cubic feet of brickwork with ⅜ to ¼-inch joints, and from 324 to 378 cubic feet of stone ashlar.

A cubic foot of common brickwork contains about eighteen bricks. See also Articles 169 and 181.

* "Concrete and Reinforced Concrete Construction." Homer A. Reid.
† "Handbook for Superintendents of Construction." H. G. Richey.

The following are useful data which have been compiled by Mr. H. G. Richey to show "What a Barrel of Portland Cement Will Do."

A barrel of Portland cement will make about 3.15 cu. ft. of neat mortar.

A barrel of Portland cement will make about 5.4 cu. ft. of mortar mixed 1 to 1.

A barrel of Portland cement will make about 8.5 cu. ft. of mortar mixed 1 to 2.

A barrel of Portland cement will make about 10.7 cu. ft. of mortar mixed 1 to 3.

A barrel of Portland cement will make about 13.5 cu. ft. of mortar mixed 1 to 4.

A barrel of Portland cement will make about 23 cu. ft. of concrete mixed 1, 3, 5.

A barrel of Portland cement will make about 26 cu. ft. of concrete mixed 1, 3, 6.

A barrel of Portland cement will make about 29 cu. ft. of concrete mixed 1, 3, 7.

A barrel of Portland cement will make about 30 cu. ft. of concrete mixed 1, 3, 8.

A barrel of Portland cement (neat) will cover about 40 sq. ft. 1 in. thick.

A barrel of Portland cement to 1 of sand will cover about 65 sq. ft. 1 in. thick.

A barrel of Portland cement to 2 of sand will cover about 92 sq. ft. 1 in. thick.

A barrel of Portland cement to 3 of sand will cover about 128 sq. ft. 1 in. thick.

A barrel of Portland cement to 2 of sand will lay about 750 bricks with ⅜-inch joints.

A barrel of Portland cement to 2 of sand will lay about 1,050 bricks with ¼-inch joints.

A barrel of Portland cement to 3 of sand will lay about 900 bricks with ⅜-inch joints.

A barrel of Portland cement to 3 of sand will lay about 1,350 bricks with ¼-inch joints.

A barrel of Portland cement to 3 of sand will lay about 2 perches of rubble stonework.

208. STRENGTH OF MORTAR.—This subject has been treated also in the articles relating to the strength of the different kinds of cement. The exact strength of mortar to resist compression is not of very great importance, as it seldom, if ever, fails in this way. The tensile and adhesive strength of mortar is more important, particularly the latter, as whenever a building has fallen from using poor mortar it has generally been on account of the failure of the mortar to adhere to the bricks or stones. Whatever

kind of mortar is used, it should be made rich and well worked, as the saving by using more sand is but a small percentage at most, and it is never safe for an architect to allow poor mortar to be used in his buildings.

The safe crushing strength of Portland cement, natural cement and lime mortar used in ½-inch joints should equal the following values in tons per square foot:

Portland cement mortar,	1 to 3,	3 months, 40 tons;	1 year, 65 tons.
Natural " "	1 to 3,	3 months, 13 tons;	1 year, 26 tons.
Lime mortar	1 to 3,	3 months, 8.6 tons;	1 year, 15 tons.

From these values we see that for granite piers, heavily loaded, only Portland cement mortar should be used. For all piers loaded with over 10 tons per square foot, and not exceeding 20 tons, natural cement mortar may be used. (See also Article 198, "The Compressive Strength of Cement Mortars.")

Lime mortar alone should never be used where any but moderate loads are to bear upon the work; nor where the full loading is to be applied before the mortar has had time to harden.

209. THE ADHESION OF MORTAR.—"The adhesion of mortars to brick or stone varies greatly with the different varieties of these materials, and particularly with their porosity. The adhesion varies also with the quality of the cement, the character, grain and quantity of the sand, the amount of water used in tempering, the amount of moisture in the stone or brick, and the age of the mortar."

Mortar adheres to both stone and brick better when they are wet (unless the temperature is below the freezing point), and the architect should always insist on having the bricks well wet down with a hose before laying. Dry bricks absorb the moisture from mortar so that it cannot harden properly, and also destroy its adhesive properties. *The wetting of the bricks* is fully of as much importance as the quality of the mortar in the brickwork. The adhesive strengths of cement mortars and lime mortars are as a rule proportional to their tensile strengths. Therefore where great adhesive strength is required to prevent sliding, as in arches, etc., either Portland or natural cement should be used, according to the importance of the work and stress to be resisted. Some years ago the walls of a brick building in New York City were pushed outward by barrels of flour piled against them, so that they suddenly fell into the street. An examination of the mortar showed that it was of poor quality,

with little adhesion to the bricks. If good mortar had been used, and if the bricks had been well wet, the failure (it should not be called an accident) would not have occurred. The adhesive and tensile strength of mortar is of great importance also in resisting wind pressure and vibration.

210. MORTAR IMPERVIOUS TO WATER.—The following proportions may be used for making a water-tight mortar, provided the water is not moving, not too cold and not impregnated with acids:

Cement.	Lime Putty.	Sand.
1 part.	½ part.	1 part.
1 part.	1 part.	3 parts.
1 part.	1½ parts.	5 parts.
1 part.	2 parts.	6 parts.

A frequent cause of the failure of masonry is the disintegration of the mortar in the outside of the joints, although this does not take place to such an extent in buildings as in engineering works. "Ordinary mortar, either lime or cement, absorbs water freely, common lime mortar absorbing from 50 to 60 per cent of its own weight, and the best Portland cement mortar from 10 to 20 per cent, and consequently they disintegrate under the action of the frost. Mortar may be made practically non-absorbent by the addition of alum and potash soap. One per cent, by weight, of powdered alum is added to the dry cement and sand and thoroughly mixed, and about 1 per cent of any potash soap (ordinary soft soap made from wood ashes is very good) is dissolved in the water used in making the mortar. The alum and soap combine and form compounds which are insoluble in water. These compounds are not acted upon by the carbonic acid of the air, and add considerable to the early strength of the mortar and somewhat to its ultimate strength."* The alum and soap are comparatively cheap and can be easily used.†

The mixture could be advantageously used in plastering basement walls and on the outside of buildings, and would add greatly to the durability of mortar used for pointing.

211. PLASTER OF PARIS IN MORTAR.—The impermeability of Portland cement mortar is increased by the addition of puzzolan cement. Plaster of Paris, which is sulphate of lime, when

* "Treatise on Masonry Construction." Ira O. Baker.

† For the effect of alum and soap in diminishing the permeability of mortars, see also results of experiments by Mr. Edward Cunningham, and Prof. W. K. Hatt in Trans. Am. Soc. of Civil Engineers, Vol. LI, pp. 127 and 128.

added to either lime or cement mortar in quantities not exceeding 5 per cent, accelerates the setting and also increases the early and the ultimate strength of mortar. Lime mortar to which plaster of Paris had been added is called "gauged" mortar. Selenetic lime, known as "Scott's cement" or "Selenetic cement," much used in England, is made by combining plaster of Paris and hydraulic lime, in the proportion of three pints of the plaster to a bushel of unslaked lime. The addition of the plaster of Paris to lime appears to increase the strength of the mortar from two to three times.

212. SUGAR IN MORTAR.—Sugar has been employed for centuries in India as an ingredient of common lime mortar, and adds greatly to the strength of the mortar.

An addition of sugar or syrup equal to one-tenth of the weight of the unslaked lime, to lime mortar, adds 50 per cent to the strength of the mortar and will cause the mortar to set more quickly. The addition of sugar to lime mortar is especially beneficial when used in very thick walls, as the lime mortar thus placed is never fully acted upon by the carbonic acid of the atmosphere.

Sugar added to natural and Portland cement mortars in the proportion of ⅛ to ¼ per cent in weight of the cement increases the strength of the mortars about 25 per cent.

Experiments made to determine the effect of sugar upon Portland cement showed that an addition of from ⅛ to 2 per cent of sugar added to Dyckerhoff's German Portland cement increased considerably its strength after three months. While the sugar retarded the setting, and favorably assisted the perfecting of the chemical changes, more than 2 per cent of it rendered the cement useless.

As the combination of sugar and lime is soluble in water, sugar should not be added to mortar that is to be used under water.

Experiments have been made also to show the effect on the strength and other properties of mortars of various other admixtures, such as alcohol, clay and loam, glycerine, lime, peat, plaster, salt, sawdust, soda, tallow, etc.*

213. EFFECT OF TEMPERATURE ON MORTARS.—Very hot weather is apt to injure mortar by causing its water to evaporate too rapidly, and thus interfere with the normal setting or hardening. Stones and bricks should be well moistened in such

* For a short bibliography of papers relating to these tests see "Concrete, Plain and Reinforced," Taylor and Thompson. Chap. XXIX, "References to Concrete Literature."

weather before bedding them so that the mortar may not dry out too fast and be reduced to a powder by the materials absorbing its moisture. Freezing does not appear to injure lime mortar *if the mortar remains frozen until it has fully set.* Alternate freezing and thawing materially damages the strength and adhesion of lime mortar, and as this is generally what happens when mortar is laid in freezing weather, it is much the safer rule for the architect to specify and see that no masonry shall be laid with lime mortar at such times.

Very cold weather retards the setting or hardening of cement mortar, and the freezing and expansion of its water tend to disintegrate it. If the temperature of mortar can be kept above the freezing point long enough to allow it to set with sufficient strength to resist the disruptive effect of frost, it may be used in freezing weather. Quick-setting Portlands are used, or hot water, or salt put in the water used in making the mortar, or the stones or bricks or sand additions are heated, or the masonry is carefully covered immediately after laying with straw or canvas or manure, etc.

Most natural cement mortars are ruined by freezing. They expand by the frost, and a settlement results with the thawing.

Portland cement mortars have their setting retarded, and their strength at short periods lowered, by freezing, but have their ultimate strength but slightly, if at all, affected.

The setting of cement mortars is hastened, and the action of frost retarded, by heating the materials.

Salt lowers the freezing point of mortar, and does not seem to affect the ultimate strength of cement mortar, where used in quantities up to 10 per cent of the weight of the water.

"Mortar composed of 1 part Portland cement and 3 parts of sand is entirely uninjured by freezing and thawing, and mortar made of natural cement, in any proportion, is entirely ruined by freezing and thawing."*

214. SALT IN MORTAR.—When it is desired to use natural cement mortar in freezing weather the mortar should be mixed with water to which salt has been added in the proportion of one pound of salt to eighteen gallons of water, when the temperature is at 32 degrees Fahr., and for each degree of temperature below 32 degrees add three additional ounces of salt. Mortar mixed with

* Trans. Am. Soc. of C. E., Vol. XVI., pp. 79-84.

such a solution does not freeze in ordinary winter weather, and hence is not injured by frost.

Builders sometimes advocate the addition of lime to natural cement mortars in cold weather to *warm them*. There would be no heating effect of the lime, however, as heat is generated in lime only when it slakes. If natural cement mortars must be used in freezing weather, the only safe way of using them is by the addition of salt, as described on opposite page, otherwise the mortars will be completely ruined by freezing.

215. CHANGE OF VOLUME IN SETTING.—Cement mortars diminish slightly in volume during the early periods of setting in air, and expand in like manner but in a less degree when under water, but the expansion and contraction are not sufficient to injuriously affect building construction. The contractions and expansions are greatest in neat cement mortars.

8. MORTAR COLORS AND STAINS.

216. THE USE OF MORTAR COLORS.—The natural color of the cement, sand and stone or gravel used affects the color of a mortar or concrete, and these separate ingredients of the complex mixture also modify the final shades even after the addition of coloring matters.

Mortars and concretes of different shades can be made by varying the amount of water used.

Sands of different colors give different final colors to mortars and concretes, the color of the other ingredients remaining the same; and the results obtained in this manner are usually far more permanent and satisfactory than those obtained from the use of artificial coloring matters.

The use of artificial coloring in mortars, however, has been in vogue, more or less, for two thousand years, but the general use of colored mortars dates from a comparatively recent period.

The object aimed at in using colored mortars in brickwork or stonework is either to get the effect of a mass of color, by concealing the joints, or else, by using a contrasting color, to emphasize the joints. Rougher bricks may also be used with nearly as good effect by using a mortar of the same color as the bricks. Chipped or uneven edges do not show as plainly with mortar of the same color as the bricks as they do when laid with white mortar.

Coloring matter is added also to cement and concrete surfaces of

all kinds, either to obtain a color effect in the cement in concrete itself, or to imitate stone of various kinds.

217. OBJECTIONS TO MORTAR COLORS.—The objection is sometimes made to the use of colored mortars that they are not as strong as white mortars and that the color always fades.

These objections undoubtedly have much truth in them when cheap colors are used and the mortar is not properly mixed, but there are better grades of mortar colors now on the market which affect the strength of the mortar to a very slight extent, and some of them, when properly mixed, hold their color fairly well.

218. KINDS OF COLORS.—Most, if not all, of the coloring materials sold under the name of "mortar colors," or stains, consist of mineral pigments put up either in the form of a dry powder or in the form of a pulp or paste.

Pulp colors are thought by some to lend themselves more readily than the dry colors to a uniform mixing with the mortar, and they are sometimes preferred for the better grades of work.

Paste or pulp stains should not be allowed to freeze, and should be kept moist by covering with water.

A great deal of colored mortar is made by using common lampblack and Venetian red, or the cheap grades of mineral paints for the coloring matter. These are very apt to fade and run and also tend to weaken the mortar, and the cheaper grades of mineral colors are not much better. Red lead, for example, is said to be injurious, even in very small quantities. The cost of the coloring matter is so small an item that only the very best grades should be used.

The principal colors used are red, brown, buff and black, although green, purple, gray, drab and other mortar colors are made.

For different grades of gray the proper kind of lampblack is used in varying proportions.

The proportions used for the dry mineral colors vary from 2 to 10 per cent of the amount of cement, according to the shade desired.

No injurious effects appear to result from the use of Prussian blue, ultramarine blue (in small quantities), burnt umber, red iron ore, yellow ochre and boneblack lampblack.

Among the lampblacks the "Germantown lampblack" is considered a desirable coloring material, on account of the small quantities necessary to obtain a good color. It is stated that even as small an amount as 1 per cent of red lead works more or less injury

to cement mortar and concrete, and that it is not advisable to use it in larger amounts.

Only moderate quantities of colors other than those mentioned should be used.

Red oxide of iron, if it contains sulphuric acid, may cause swelling. Peroxide of manganese is sometimes used to produce shades of black and bluish gray; the best raw iron oxide to produce red; caput mortuum (expensive) to produce bright red; Venetian red to produce a cheaper red; the best roasted iron oxide to produce brown; and ochre to produce buff.

The following are useful data* compiled by Mr. Charles Carroll Brown, and bearing upon this subject:

"Cement manufacturers recommend the following quantities per 100 pounds of cement:

Black, 2 pounds excelsior carbon black.

Blue, 5 to 6 pounds ultramarine.

Brown, 6 pounds roasted iron oxide.

Gray, ½ pound lampblack.

Green, 6 pounds ultramarine.

Red, 6 to 10 pounds raw iron oxide.

Bright red, 6 pounds Pompeiian red.

Yellow or buff, 6 to 10 pounds yellow ochre.

"It is said that unfading colored cement can be made by mixing with the raw materials before burning chromic oxide for green, oxide of copper for a blue-green, and equal parts of oxides of iron, manganese and cobalt for a black color. Such cements are not on the general market, however. Finely ground oxide of manganese added to the mortar will give a black color and not weaken the concrete. Venetian red and lampblack will fade.

"White cements are often asked for. There is some difference in shade of Portland cements and puzzolan cements are usually the lightest. They are not satisfactory for greatly exposed work. An English patent makes a white cement by mixing one part of kaolin, a clay without iron, three to five parts of white chalk, and two to five per cent of gypsum, or three to five per cent of magnesium chloride. The mixture is burned as any other cement is burned. The resulting cement would probably not stand severe exposure to the weather. Lafarge, a French "grappier" cement, is very light

* "Handbook for Cement Users." Edited by Charles Carroll Brown. Published by Municipal Engineering Company, Indianapolis and New York.

colored. The use of a white marble dust in place of sand and puzzolan or lighter cements produces the best results yet obtained. Sulphate of barium, oxide of zinc and sulphate of lead produce a grayish white color, but their permanence is not guaranteed."

The following table* is given by Mr. Lewis Carlton Sabin, and shows the colors given to Portland cement mortar containing two parts yellow river sand to one part cement.

TABLE XVI.

Colors for Portland Cement Mortars.

Cost of Coloring Matter per lb. ct.	Dry material used	Weight of Dry Coloring Matter to 100 Pounds of Cement			
		½ pound	1 pound	2 pounds	4 pounds
15	Lamp Black	Light Slate	Light Gray	Blue Gray	Dark Blue Slate
50	Prussian Blue	Light Green Slate	Light Blue Slate	Blue Slate	Bright Blue Slate
20	Ultramarine Blue	....	Light Blue Slate	Blue Slate	Bright Blue Slate
3	Yellow Ochre	Light Green	....	....	Light Buff
10	Burnt Umber	Light Pinkish Slate	Pinkish Slate	Dull Lavender Pink	Chocolate
2½	Venetian Red	Slate, Pink Tinge	Bright Pinkish Slate	Light Dull Pink	Dull Pink
2	Chattanooga Iron Ore	Light Pinkish Slate	Dull Pink	Light Terra-Cotta	Light Brick Red
2½	Red Iron Ore	Pinkish Slate	Dull Pink	Terra-Cotta	Light Brick Red

Mr. Homer A. Reid has compiled a list† of the usual proportions by weight of different coloring matters to be added to 1 sack of cement and 2 cubic feet of sand (a 1 to 2 mixture) to secure different colored mortars.

The list gives the weight of coloring matter to 1 sack of cement for a 1 to 2 mixture, and is as follows:

FOR WHITE STONE:

White Portland cement, 1 part;
Pulverized lime, ¼ part;
Pulverized marble, ½ part;
Light-colored sand, 1 part.

On account of the inferiority of white Portland cement, the above is seldom used.

* "Cement and Concrete." Lewis Carlton Sabin.
† "Concrete, and Reinforced Concrete Construction." Homer A. Reid.

FOR BLACK STONE:
3 lbs. Excelsior carbon black, or
11 lbs. manganese dioxide.

GRAY STONE:
1 lb. Excelsior carbon black, or
½ lb. Germantown lampblack (boneblack).

BROWN STONE:
4 to 5 lbs. brown ochre, or
6 lbs. roasted iron oxide, best quality.

BUFF STONE:
4 lbs. yellow ochre.

RED STONE:
5 lbs. violet iron oxide (raw).

BRIGHT RED STONE:
From 5½ to 7 lbs. English or Pompeiian red.

YELLOW STONE:
5½ lbs. ochre.

GREEN STONE:
6 lbs. of greenish blue ultramarine blue.

BLUE STONE:
2 lbs. ultramarine blue.

DARK BLUE STONE:
4 lbs. ultramarine blue.

PURPLE STONE:
5 lbs. Prince's metallic.

VIOLET STONE:
5½ lbs. violet oxide of iron.

In the construction of six emplacements at Fort Wadsworth, New York, the exterior surface was coated with colored mortar mixed according to the following formulas:

FOR GREEN COLOR:
Cement, 1 bbl.;
Sand, 2 bbls.;
Ultramarine blue, 50 lbs.;
Yellow ochre, 73 lbs.;
Soft soap, 7 lbs.;
Alum, 7 lbs.

FOR SLATE COLOR:
Cement, 1 bbl.;
Sand, 2 bbls.;
Lampblack, 50 lbs.;
Ultramarine blue, 35 lbs.;
Soft soap, 7 lbs.;
Alum, 7 lbs.

After completion of the batteries, the color became much lighter with age. It was found that spraying with linseed oil very materially deepened its shade.

219. MIXING.—Mortar colors, whether in dry or paste form, should not be mixed with lime until the latter has been slaked at least forty-eight hours, and the best way is to keep a lot of lime putty on hand and mix the color with it as needed. Mortar colors should never be mixed with hot lime.

For coloring lime mortar the colors should first be mixed with dry sand, then the cold slaked lime added and again mixed thoroughly. It is very important that the colors be uniformly mixed.

For cement and concrete work the stain should be thoroughly mixed with the cement, the sand then added, and the whole thoroughly mixed dry. When gravel or stone is used it should be mixed dry with the sand and coloring matter, and then the whole should be thoroughly mixed until the color of the mass is uniform. After this the water should be gradually added as needed, and the mixing continued until the requisite consistency is obtained.

The color of the mortar looks different in the bed than when dry. To get the final color of the mortar a little should be taken from the bed and permitted to dry thoroughly, when the permanent color may be seen. The gloss of the water makes the mortar look darker.

The amount of coloring matter required to stain a given quantity of mortar varies with the different colors and brands. The following quantities may be taken as the average amounts required in laying one thousand bricks with spread joints:

Red, buff or brown, 50 pounds.

Black, from 40 to 45 pounds.

When buttered joints are used:

Red, buff or brown, 40 pounds.

Black, from 25 to 35 pounds.

The following additional data* give the weight of coloring matter to 1 barrel of cement, advised by good authorities:

GRAY, use 2 pounds of Germantown lampblack to a barrel of cement.

BLACK, use 45 pounds of manganese dioxide to a barrel of cement.

BLUE, use 19 pounds of ultramarine to a barrel of cement.

GREEN, use 23 pounds of ultramarine to a barrel of cement.

RED, use 22 pounds of iron oxide to a barrel of cement.

BRIGHT RED, use 22 pounds of Pompeiian or English red to a barrel of cement.

VIOLET, use violet oxide of iron 22 pounds to a barrel of cement.

YELLOW and BROWN, use 22 pounds of ochre to a barrel of cement.

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* "Handbook for Superintendents of Construction." H. G. Richey.

CHAPTER V.

Building Stones.

I. INTRODUCTORY.

220. THE SUBJECT IN GENERAL.—It is important that an architect should have some knowledge of the nature of the different kinds of stone in order that he may know what kind it is best to use or not to use under any given circumstances. While he is not expected to possess the special knowledge of a geologist, a mineralogist or a chemist, nor to determine the exact composition of a stone, he is supposed to know enough of the subject to specify stones which have sufficient strength and durability, and which will not become discolored by chemical changes in their constituents.

This general knowledge of building stones requires not only a study of their mineral constituents and of their structure, but also much accurate observation and experience.

221. PRODUCTION AND VALUE OF DIFFERENT KINDS OF STONE.—The following table* shows the value of the different kinds of stone produced in the United States from 1896 to 1906, inclusive:

TABLE XVII.

VALUE OF THE DIFFERENT KINDS OF STONE PRODUCED IN THE UNITED STATES, 1896-1906.

Year	Granite	Trap rock	Sandstone	Bluestone	Marble	Limestone	Total
1896..........	$7,944,994	....	$4,023,199	a$750,000	$2,859,136	$8,387,900	$23,965,229
1897..........	8,905,075	....	4,065,445	a900,000	3,870,584	9,135,567	26,876,671
1898..........	9,324,406	....	4,724,412	a1,000,000	3,629,940	9,956,417	28,635,175
1899..........	10,343,298	$1.275,041	b4,910,111	815,284	4,011,681	13,889,302	35,244.717
1900..........	10.969,417	1,706,200	b5,272,865	1,198,519	4,267,253	13,556,523	36,970,777
190[illegible]....... ..	14,266,104	1,710,857	b6,974,199	1,164,481	4,965,699	18,202,843	47,284,183
1902..........	16,083,475	2,181,157	b9,430,958	1,163,525	5,044,182	20,895,385	54,798,682
1903..........	15,703,793	2,732,294	b9,482,802	1,779,457	5,362,686	22,372,109	57,433,141
1904..........	17,191,479	2,823,546	b8,482,162	1,791,729	6,297,835	22,178,964	58,765,715
1905..........	17,563,139	3,074,554	b8,075,149	1,931,625	7,129,071	26,025,210	63,798,748
1906..........	18,569,705	3,736,571	b7,147,439	2,021,898	7,582,938	27,320,243	66,378,794

a Estimated. b Does not include the value of grindstones and whetstones.

* Mineral Resources of the United States for 1906. Article on "Stone," by A. T. Coons.

The table shows that the total reported value of stone quarried in the United States in 1906, exclusive of products mentioned on preceding page, was $66,378,794. The corresponding value for 1905 was $63,798,748, an increase for 1906 of $2,580,046. In 1905 the gain was $5,033,033; in 1904 it was only $1,332,574; in 1903 it was $2,634,459, and in 1902 it was $7,514,499. The increase for 1906 over 1896 is $42,413,565. The production of 1902, 1903, 1904 and 1905 was affected by strikes in the building trades, but continued increase in the production of crushed stone and, in 1905, of stone for furnace flux caused increased values in the totals. In 1906 almost all the producers, and especially the small quarrymen, stated that the cost of production had increased on account of increased cost of supplies, high wages and lack of common labor; and that less stone was produced on account of the cheaper production and increased use of concrete, cement and concrete blocks.

Granite, trap rock, marble, bluestone and limestone increased in value, while the value of sandstone decreased.

Granite, trap rock, etc., represented 33.60 per cent of the total output in 1906, and increased in value from $20,637,693 in 1905 to $22,306,276 in 1906, a gain of $1,668,583. Trap rock increased in value from $3,074,554 in 1905 to $3,736,571 in 1906, or $662,017. Granite increased from $17,563,139 in 1905 to $18,569,705 in 1906, a gain of $1,006,566.

Sandstone and bluestone represented 13.80 per cent of the total stone output in 1906. Their value in 1906 was $9,169,337, which, compared with a value of $10,006,774 in 1905, shows a decrease of $837,437. Bluestone increased in value from $1,931,625 in 1905 to $2,021,898 in 1906, a gain of $90,273. Sandstone decreased in value from $8,075,149 in 1905 to $7,147,439 in 1906, a loss of $927,710.

Marble represented 11.42 per cent of the total stone output in 1906, the total value being $7,582,938; in 1905 the value was $7,129,071, a gain for 1906 of $453,867.

Limestone represented 41.16 per cent of the total stone output of the United States in 1906, and was valued at $27,320,243; in 1905 the value was $26,025,210, a gain for 1906 of $1,295,033.

222. GOVERNMENT CLASSIFICATION IN STONE PRODUCTION.—For simplicity of treatment the kinds of stone covered by the figures given are classified as granite, trap rock, sandstone, bluestone, limestone and marble.

Granite includes true granites and other igneous rocks, as gneiss, mica schist, andesite, syenite, trachyte, quartz porphyry, lava, tufa, diabase, trap rock, basalt, diorite, gabbro, and a small quantity of serpentine. Rocks of these kinds are as a rule quarried commercially in quantities too small to permit their being tabulated separately, but the trap rock output of California, Connecticut, Massachusetts, New York, New Jersey and Pennsylvania represents an important industry, and it is therefore considered advisable to show the value of this stone separately. The trap rock from California includes a considerable quantity of basalt.

Sandstone includes the quartzites of South Dakota and Minnesota, but the fine-grained sandstones of New York and Pennsylvania, known to the trade as bluestone, are the product of a separate industry, and their production is shown apart from that of the other sandstone. This bluestone is also quarried in New Jersey and West Virginia. In Kentucky most of the sandstone quarried and sold is known locally as freestone. The figures given for sandstone do not include the value of the grindstones, whetstones and pulpstones, made from sandstone quarried in Michigan, Ohio and West Virginia. Neither does the total sandstone value include sandstone crushed into sand and used in the manufacture of glass and as molding sand.

Limestone does not include limestone burned into lime, bituminous limestone, nor limestone entering into the manufacture of Portland cement. It includes, however, a small quantity of stone sold locally as marble.

Marble includes a small quantity of serpentine quarried and sold as marble in Georgia, Washington and Pennsylvania.

The values given represent the net value of the stone to the quarrymen, that is, the selling value exclusive of any freight charges. When the stone is cut or dressed by the quarrymen and sold in this manner, the value of the dressed stone is given. This applies especially to the stone quarried for use as building and monumental stone. The value of crushed stone is the net value crushed at the point of shipment.

223. RANK OF STATES AND TERRITORIES IN VALUE OF STONE PRODUCTION.—In the Appendix are given tables showing the value of the various kinds of stone produced in 1905 and 1906, by States and territories, and a table showing the *rank* of the States and territories in these years,

according to value of production, and the percentage of the total produced by each State or territory.

From this latter table it is seen that Pennsylvania, producing chiefly limestone and sandstone but also granite and marble, reported the greatest value of stone output for the entire United States, which was 13.27 per cent of the total; Vermont, producing granite, marble and a small quantity of limestone, was second, with 11.34 per cent of the total; New York, producing sandstone, limestone, granite and marble, ranked third; Ohio, producing limestone and sandstone, was fourth; Massachusetts, producing granite, marble, sandstone and limestone, was fifth; Indiana was sixth, followed by Illinois, Maine, California and Missouri, each producing stone valued at over $2,000,000.

224. TOTAL VALUE OF STONE USED FOR VARIOUS PURPOSES.—The following table is given to show the total values of the stone used for various purposes in 1905 and 1906; only those values are given which are for uses common to two or more varieties of stone:

TABLE XVIII.

VALUE OF GRANITE, SANDSTONE, LIMESTONE AND MARBLE USED FOR VARIOUS PURPOSES IN 1905 AND 1906.

1905

Kind	Building (rough and dressed)	Monumental (rough and dressed)	Flagstone	Curbstone	Paving stone	Crushed stone
Granite	$7,298,797	$3,842,368	$38,838	$762,430	$2,133,873	$4,923,706
Sandstone	4,702,189	....	1,221,348	1,044,983	716,682	1,008,270
Limestone	5,312,183	....	127,801	283,426	231,785	10,487,638
Marble	2,927,640	2,270,217	....	....	....	....
Total	$20,240,809	$6,112,585	$1,387,987	$2,090,839	$3,082,340	$16,419,614

1906

Kind	Building (rough and dressed)	Monumental (rough and dressed)	Flagstone	Curbstone	Paving stone	Crushed stone
Granite	$8,536,420	$4,116,075	$50,609	$787,237	$1,652,927	$5,504,327
Sandstone	4,275,669	....	1,097,438	1,074,369	694,995	889,894
Limestone	5,092,916	....	109,632	289,615	531,275	11,073,265
Marble	2,782,620	2,657,813	....	....	....	....
Total	$20,687,625	$6,773,888	$1,257,679	$2,151,221	$2,879,197	$17,467,486

From this table it appears that the total value of building stone increased from $20,240,809 in 1905 to $20,687,625 in 1906, a gain of $446,816. Granite represented in 1906 41.26 per cent of this

building stone; limestone, 24.62 per cent; sandstone, 20.67 per cent; and marble, 13.45 per cent.

Monumental stone increased in value from $6,112,585 in 1905 to $6,773,888 in 1906, a gain of $661,303. Of the monumental stone 60.76 per cent was granite in 1906 and 39.24 per cent marble.

Flagstone in 1906 decreased in value $130,308, or from $1,387,987 in 1905 to $1,257,679 in 1906. Sandstone represented 87.26 per cent of the flagstone output in 1906. The proportion of granite and limestone was small.

Curbstone increased in value from $2,090,839 in 1905 to $2,151.221 in 1906, or $60,382. Sandstone represented 49.94 per cent of this output in 1906; granite, 36.60 per cent; and limestone, 13.46 per cent.

Paving stone decreased in value from $3,082,340 in 1905 to $2,879,197 in 1906, a loss of $203,143. Granite was 57.40 per cent of the total paving material; sandstone, 24.14 per cent; and limestone, 18.46 per cent.

225. DISTRIBUTION OF BUILDING STONES IN THE UNITED STATES.—A general consideration of the geographical distribution of stones of various kinds throughout the United States is of interest and importance in the study of building stones.

The following table* illustrates this distribution and the consequent resources of the various States, and mentions only those stones "which it seemed safe to assume occur in such quantities or under such conditions as to render them of present or prospective value for the purposes under discussion. For the purpose of easy reference, the States are arranged alphabetically. A name in italics indicates that the stone is, or has been, actively quarried within a comparatively recent period."

TABLE XIX.

Distribution of Building Stones in the United States.

State or Territory.	Present and Prospective Resources.
Alabama	Marble, limestone, granite, sandstone.
Arizona	*Onyx marble,* limestone, granite, trappean and volcanic rocks, and *sandstones.*
Arkansas	Marble, limestone, *syenite.*
California	*Serpentine (verdantique marble), onyx marble, marble, limestone, granite, volcanic rocks* and *tuffs, sandstone, slate.*

* "Stones for Building and Decoration," by George P. Merrill. John Wiley & Sons, New York, 1903.

TABLE XIX (*Continued*).

Colorado	*Marble, limestone, granite,* trappean and *volcanic rocks, sandstone, quartzite, rhyolite tuff.*
Connecticut	Soapstone, serpentine (verdantique marble), marble, *granite* and *gneiss, diabase, sandstone.*
Delaware	Marble, *gneiss.*
Florida	Shell and oolitic limestone.
Georgia	*Marble, granite, gneiss,* sandstone, *slate.*
Idaho	Limestone, *marble,* granite, trappean and volcanic rocks, sandstone.
Illinois	*Limestone* and *dolomite, sandstone.*
Indiana	*Limestone, dolomite, sandstone.*
Indian Territory	Limestone, dolomite, sandstone.
Iowa	*Gypsum, limestone, dolomite, sandstone.*
Kansas	*Limestone, dolomite, sandstone.*
Kentucky	*Limestone, dolomite, sandstone.*
Louisiana	Limestone, sandstone.
Maine	Soapstone, serpentine (verdantique marble), limestone, *granite, gneiss, diabase,* norite, *gabbro,* quartz, porphyry, sandstone, *slate.*
Maryland	*Soapstone, serpentine (verdantique marble), marble, granite, sandstone, slate.*
Massachusetts	*Soapstone, serpentine (verdantique marble), marble, granite, gneiss,* quartz porphyry.
Michigan	*Limestone, dolomite, granite, gneiss, sandstone, slate.*
Minnesota	*Limestone, dolomite, granite,* gneiss, *sandstone, slate.*
Mississippi	Limestone, sandstone.
Missouri	*Limestone, dolomite, granite, diabase,* quartz porphyry, *sandstone.*
Montana	Limestone, dolomite, *granite,* gneiss, trappean and volcanic rocks, *sandstone.*
Nebraska	*Limestone, dolomite, sandstone.*
Nevada	Limestone, dolomite, granite, trappean and *volcanic* rocks, *sandstone.*
New Hampshire	*Soapstone,* limestone, *granite,* slate.
New Jersey	Serpentine, limestone, dolomite, *marble,* granite, *gneiss, diabase, sandstone, slate.*
New Mexico	*Serpentine (riccolite),* limestone, marble, trappean and volcanic rocks, sandstone, granite.
New York	Soapstone, *serpentine (verdantique marble), limestone, dolomite, marble, granite, gneiss, norite, sandstone, slate.*
North Carolina	Soapstone, serpentine, limestone, dolomite, marble, *granite,* gneiss, diabase, *norite, sandstone.*
North Dakota	Limestone, dolomite, sandstone.
Ohio	*Limestone, dolomite, sandstone.*
Oklahoma	Limestone, dolomite, sandstone.

TABLE XIX (*Continued*).

Oregon	Limestone, dolomite, granite, *trappean* and volcanic rocks, *sandstone.*
Pennsylvania	*Soapstone, serpentine, limestone, dolomite, marble,* granite, *gneiss, diabase,* quartz porphyry, *sandstone, conglomerate, slate.*
Rhode Island	Limestone, dolomite, *granite, gneiss.*
South Carolina	Limestone, *granite,* gneiss.
South Dakota	*Limestone,* sandstone, *quartzite.*
Tennessee	*Limestone, marble, granite,* diorite, sandstone.
Texas	*Limestone,* marble, *granite,* trappean and volcanic rocks, *sandstone.*
Utah	Limestone, *marble, granite,* trappean and volcanic rocks, sandstone.
Vermont	*Soapstone,* serpentine (verdantique marble), *marble, gneiss, slate.*
Virginia	*Soapstone,* limestone, marble, *granite, gneiss, diabase, granite, gneiss, slate.*
Washington	Limestone, marble, granite, trappean and volcanic rocks, *sandstone.*
West Virginia	*Limestone, sandstone.*
Wisconsin	*Dolomite, granite, gneiss,* quartz porphyry, *sandstone.*
Wyoming	Limestone, *granite,* trappean and volcanic rocks, sandstone.

226. THE MINERALS OF BUILDING STONES.—One should be generally familiar with the more common mineral substances which compose the more important kinds of work, in order to understand the relative value of different stones for building, monumental or other purposes.

Any rock is composed, as a rule, of several different minerals in a state of aggregation, and these minerals are in turn made up of two or more substances known as elements. There are seventy-four known elements which combine to form all known matter. The eight most important, in order of abundance, are the following: oxygen, 47.13 per cent; silicon, 27.89 per cent; aluminum, 8.13 per cent; iron, 4.71 per cent; calcium, 3.53 per cent; sodium, 2.68 per cent; magnesium, 2.64 per cent; potassium, 2.35 per cent.

The elements generally exist in combination with one another, forming mineral substances. There are known, described and named about two thousand different combinations, but more than 95 per cent of all the rocks generally considered in reports and treatises on building stones are composed of various combinations of fourteen minerals.

Minerals are distinguished from one another by (1) their chemical composition, (2) their crystallization and (3) their physical properties.

The chemical composition is obtained by a chemical analysis.

All minerals, which occur in crystals, crystallize under one of six well-defined systems.

The most important physical properties are color, luster, cleavage, streak and hardness.

Minerals are referred to a "scale of hardness" of ten units, composed of common or well-known minerals, as follows: (1) talc, (2) gypsum, (3) calcite, (4) fluorite, (5) apatite, (6) orthoclase, (7) quartz, (8) topaz, (9) sapphire and (10) diamond. The hardness of any mineral is determined by its ability to scratch the members of this scale, and the degree of hardness is expressed by the number of the mineral in the scale, minerals of intermediate hardness being expressed by fractions.

The important minerals and groups of minerals generally considered in reference to building stone are (1) quartz, (2) feldspar, (3) mica, (4) amphibole, (5) pyroxene, (6) chlorite, (7) olivine, (8) talc, (9) calcite, (10) dolomite, (11) magnetite, (12) hematite, (13) limonite and (14) pyrite.

These are fully described in the numerous works on mineralogy and it is not possible or desirable, in the limits of one chapter on building stones, to enter into any discussion of their properties.

227. ROCK CLASSIFICATION.—All the rocks now used for constructive purposes may be classified under the following heads:*

TABLE XX.

CLASSIFICATIONS OF ROCKS USED FOR CONSTRUCTIVE PURPOSES.

A. IGNEOUS ROCKS; ERUPTIVE.

(1) Massive with Quartz and Orthoclase:
- (*a*) Granite and Granite Porphyries.
- (*b*) Quartz Porphyries.
- (*c*) Liparites.

(2) Massive without Quartz:
- (*a*) Syenite.
- (*b*) Quartz-free Porphyries.
- (*c*) Trachytes and Phonolites.

(3) Plagioclase Rocks:
- (*a*) Diorites and Diorite Porphyries.
- (*b*) Diabases, Gabbros, Melaphyrs and Basalts.

* "Stone for Building and Decoration." George P. Merrill.

TABLE XX (*Continued*).

(4) Rocks without Feldspars:
- (*a*) The Peridotites (Serpentine in part).
- (*b*) The Pyroxenites (Soapstone in part).

B. AQUEOUS ROCKS.

(1) Sedimentary:
- (*a*) Siliceous: Sandstones, Conglomerates, Breccias, Clay-slates and Volcanic Tuffs.
- (*b*) Calcareous: Limestones and Dolomites (including the Marbles).

(2) Chemical precipitates: Onyx Marbles and Travertines; Gypsum and Alabaster.

C. ÆOLIAN ROCKS.

Æolian Limestones (included under (*b*) above).

D. METAMORPHIC ROCKS.

- (*a*) The Gneisses and crystalline Schists (included with Granite).
- (*b*) The Marbles (included here with the Limestones).
- (*c*) The Serpentines (Verdantique Marbles in part).

228. GEOLOGICAL RECORD.—In considering various building stones, they are frequently referred to the various rock formations in the earth's crust in which they occur, and for the convenience of those who are not familiar with the order of succession of these formations, Table XXI is given on following page.

2. GRANITE.

229. GRANITE.—*General Description.*—The short descriptions* in the following articles of the principal building stones of this country, with the localities in which they are quarried, will enable the young architect to get some idea of their composition and characteristics and, it is hoped, assist him in making a judicious selection of stones for special cases. The stones are classed according to their structure and composition. The granites are massive rocks occurring most frequently as the central portions of mountain chains. They are hard, granular stones, composed principally of quartz, feldspar and mica, in varying proportions. When the stone

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* For a complete work on the subject the reader is referred to "Stones for Building and Decoration," by George P. Merrill, Ph.D.; John Wiley & Sons, publishers. Much valuable information relating to building stones may also be found in the various numbers of the monthly periodical, *Stone.*

The following recent publications on building stones will also be found of great interest and value:

"Building and Ornamental Stones of Wisconsin," by E. R. Buckley, Bulletin No. 4 of the Wisconsin Geological and Natural History Survey, 1898.

"The Quarrying Industry of Missouri," by E. R. Buckley and H. A. Buehler, Vol. II, 2d Series of the Missouri Bureau of Geology and Mines, 1904.

"The Granites and Gneisses of Georgia," by Thomas L. Watson, Bulletin No. 9-A, of the Geological Survey of Georgia, 1902.

"The Building and Ornamental Stones of North Carolina," by Thomas L. Watson

TABLE XXI.

GEOLOGICAL RECORD, OR ORDER OF SUCCESSION OF THE ROCKS COMPOSING THE EARTH'S SURFACE.

	Quarternary, or Post-tertiary	The Age of Man	Recent, or Terrace Champlain Glacial, or Drift	
	Tertiary, or Cenozoic	Age of Mammals	Tertiary	Pliocene Miocene Eocene
	Secondary, or Mesozoic	Age of Reptiles		Laramie
			Cretaceous	Upper Middle Lower
			Jurassic	Wealden Upper oolite Middle oolite Lower oolite Upper Lias Marlstone Lower Lias
			Triassic	Keuper Muschelkalk Bunter Sandstone
Primary, or Paleozoic Time	Carboniferous Age		Permian	Permian
			Carboniferous	Upper Coal-measures Lower Coal-measures Millstone Grit
			Subcarboniferous	Upper Lower
	Devonian, or Age of Fishes		Catskill	Catskill
			Chemung	Chemung Portage
			Hamilton	Genesee Hamilton Marcellus
			Corniferous	Corniferous Schoharie Cauda-galli
	Silurian, Age of Invertebrates	Upper Silurian	Oriskany	Oriskany
			Lower Helderberg	Lower Helderberg
			Salina	Salina
			Niagara	Niagara Clinton Medina
		Lower Silurian	Trenton	Cincinnati Utica Trenton
			Canadian	Chazy Quebec Calciferous
	Cambrian, or Primordial	Upper Middle Lower		Potsdam Georgian St. John's
			Archæan, Pre-Cambrian	Huronian Laurentian

contains a large proportion of quartz it is very hard and difficult to work, but when there is a considerable proportion of feldspar it works more easily.

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and Francis B. Laney with the collaboration of George P. Merrill, Bulletin No. 2, North Carolina Geological Survey, 1906.

"The Fire-Resisting Qualities of Some New Jersey Building Stones," by W. E. McCourt, in Annual Report of the State Geologist, 1907.

"The Granites of Maine," by T. Nelson Dale, with an introduction by Geo. O. Smith, Bulletin No. 313, United States Geological Survey, 1907.

"The Building and Decorative Stones of Maryland," by E. B. Mathews and Geo. P. Merrill. Vol. II, Special Publications, Geological Survey of Maryland, 1898.

"The Chief Commercial Granites of Massachusetts, New Hampshire and Rhode Island," by T. Nelson Dale, Bulletin of the United States Geological Survey, 1908.

"The Granites of Vermont," by T. Nelson Dale, Bulletin of the United States Geological Survey, 1908.

"The Granites of Connecticut," by T. Nelson Dale. To be published in 1909.

The color of a granite is determined principally by the color of the feldspar, but the stone may also be light or dark, from the light or dark mica in it. The usual color of granite is either light or dark gray, although all shades from light pink to red are found in different localities.

The light fine-grained stones are the strongest and most durable, although almost every granite has sufficient strength for ordinary building construction. It generally breaks with regularity and may be readily quarried, but it is extremely hard and tough and works with great difficulty, so that it is a very expensive kind of stone to use for cut work. It is impossible to do fine carving on most of the granites. They rank among the best stones for foundations, base-courses, water-tables, etc.; for columns and all places where great strength is required; and for steps, thresholds and flagging, for which last-mentioned purpose they can often be split.

Excellent varieties of granite may be obtained from any of the New England States, from most of the Southern States, from the Rocky Mountain region, and from California and Minnesota.

As a rule granite can be quarried in any size required. Stones from new quarries should be analyzed to see if they contain iron, in which case it is dangerous to use them for ornamental purposes until their weathering qualities have been thoroughly tested by exposing them for a long time to the weather. If the iron is a sulphurate it is quite sure to stain them.

Gneiss (pronounced like "nice") has the same composition as granite, but the ingredients are arranged in layers which are approximately parallel. For this reason the rocks split so as to give parallel flat surfaces, making the stones valuable for foundation walls, street paving and flagging. Gneiss is often mistaken for granite, and is frequently called by quarrymen *stratified* or *bastard* granite.

Syenite also is a rock resembling granite, but containing no quartz. It is a hard, durable stone, generally of fine grain and light gray color. The principal syenite quarries in this country are near Little Rock and Magnet Cone, Arkansas.*

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* In many books and papers treating on granite, syenite is described as a rock consisting of quartz, feldspar and hornblende, the latter taking the place of the mica in the true granites. According to the modern methods of classification such rocks are called "hornblende granite."

"The name 'syenite' takes its origin from Syene, Egypt, but the stone from which it was named has been found to contain more mica than hornblende. According to recent lithologists the Syene rock is a hornblende-mica granite, while true syenite, as above stated, is a quartzless rock."—*Merrill.*

All three of the above-mentioned kinds of stone are badly affected by fire, large pieces breaking off and the stone cracking badly.

Fox Island, Me., Groton, Conn., Woodstock, Md., St. Cloud, Minn., and Nova Scotia granites are spoiled at 900° Fahr. Hallowell, Me., Red Beach, Me., Oak Hill, Me., and Quincy, Mass., granites are spoiled at 1,000° Fahr. The granites standing the highest fire tests are those from Barre, Vt., Concord, N. H., Ryegate, Vt., Mt. Desert, Me.

230. DESCRIPTION OF SOME IMPORTANT GRANITES.—

MAINE.

The quarries of Vinalhaven and Hurricane Islands, Knox Co., Maine.— These and the adjacent islands have been known collectively as the Fox Islands and their granite as Fox Island granite.

These quarries are the most extensive in the country; texture of stone rather coarse; color, gray; stone contains a small amount of hornblende. It takes a good and lasting polish, and is well adapted to all kinds of ornamental work and to general building purposes. It has been used extensively all over the country for building and monumental purposes.

The product is used for docks, bridges, piers, buildings and monuments. The thin sheets and much of the waste are made into paving blocks 12 by 4 by 7 to 8 inches. The principal markets are New York, Philadelphia and Washington. Specimen structures in which Vinalhaven granite was used are: The new post-office building, Washington, D. C.; Masonic Temple, Philadelphia; savings-bank building, Wilmington, Del.; new Board of Trade building, Chicago; new post-office and custom-house, Brooklyn, N. Y.; Manhattan Bank building, New York. These quarries furnished also the stone for the new custom-house in New York, for the Altman building, Thirty-fourth street and Fifth avenue, and for the West street office-building, West, Cedar, and Albany streets, New York, and for some docks in the same city.

These quarries supplied also 8 columns, 51½ to 54 feet long by 6 feet in diameter, for the Cathedral of St. John the Divine in New York. It was intended that they should each be of one piece, but as both the direction of the rift at the quarry and architectural principles required that they be cut with their long axes at right angles to the rift, the stress in the great lathe came upon the weakest part of the stone. However, as the first stone put into the lathe broke with a long diagonal fracture, it became evident that the chief difficulty was that the stone had been subjected to too great a torsional stress by the application of rotary power from one end only. It therefore became necessary to make each column in two sections, each about 26 feet long.

Specimen buildings in which granite from the Hurricane Islands quarries was used are: The Suffolk County court-house in Boston; the St. Louis post-office and custom-house; two buildings for the Naval Academy at Annapolis, Md.; the United States custom-house, New York; Pennsylvania Railroad station and base course of Bulletin building, Philadelphia.

Other Knox Co. quarries are as follows: The High Isle quarry; granite

slightly pinkish, medium gray, and of medium to coarse, even-grained texture; used in new Wanamaker stores, Philadelphia.

The Dix Island quarries; granite somewhat dark gray shade, and of medium to coarse, even-grained texture; used in United States Treasury Department extension at Washington, basement of Charleston, S. C., custom-house, the New York and Philadelphia custom-houses.

The Sprucehead quarry; granite with conspicuous black and white particles, and of medium to coarse even-grained texture; used in Carnegie Library building, Allegheny, Pa., new post-office and custom-house at Atlanta, Ga., the Mutual Life Insurance Company's building, New York.

The Clark Island quarry; granite bluish gray, fine to medium texture; used in Hartford, Conn., and Buffalo, N. Y., post-offices, and Standard Oil Company's building, New York.

The Long Cove quarry; granite bluish gray; used in Albany, N. Y., post-office, and Bates building, Philadelphia.

Hallowell, Kennebec Co., Maine.—This stone is celebrated for its beauty and fine working qualities, and is in great demand for monuments and statuary. It is a fine light gray rock, comparatively pure, the principal constituents being quartz, feldspar and mica. Has been used extensively all over the country.

About seven-eighths of the product go into building and one-eighth goes into carved work. The principal markets are Chicago and New York. Specimen buildings: Albany, N. Y., Capitol; Hall of Records (including its statuary), New York; Brooklyn Savings Bank building, New York; Masonic Temple, Boston; academic and library buildings at United States Naval Academy, Annapolis, Md.; Illinois Trust Company's building, Chicago; Northwestern Insurance Company's building, Milwaukee; post-office at Allegheny, Pa.; American Surety Company's building, New York; Shawmut Bank building, Boston; Marshall Field building, Chicago.

Hallowell granite is of fine texture, and especially suited to building work, lending itself remarkably well to statuary and delicate ornamental carving.

The quarry consists of three principal openings, the largest being 800 feet long, 400 feet wide and 60 feet deep, and is an excellent example of the gradual increase in thickness of sheets of granite, as they vary from 6 inches at the top to 14 feet at the bottom, permitting the quarrying of stones of all shapes and sizes.

Among the largest stones quarried have been the following:

1 piece	4½	by	4½	by	50	feet	long,	weighing	100	tons	in the	rough.
8 pieces	4½	"	4½	"	36	"	"	"	72	"	"	"
16 "	4½	"	3.8	"	36	"	"	"	60	"	"	"
1 piece	18	"	18	"	2.0	"	"	"	64	"	"	"
2 pieces	8	"	18.6	"	3.10	"	"	"	55	"	"	"
1 piece	8.9	"	6.6	"	5.8	"	"	"	34	"	"	"
2 pieces	32.7	"	7.3	"	1 4	"	"	"	31	"	"	"
1 piece	13.5	"	10.11	"	2.1	"	"	"	30	"	"	"

The crushing strength of this granite is about 17,500 pounds per square inch.

Cumberland County, Maine, Quarries.—Brunswick; medium gray; fine, even-grained; used in chapel of Bowdoin College, Brunswick, Me., and First Parish Church, Portland, Me.

Freeport; medium gray, slight bluish tinge, fine even grain; monumental work.

Pownal; light gray, fine even grain, used in chapel at corner of Seventieth street and Central Park, New York; Van Norden Trust Co.'s building, Sixtieth street and Fifth avenue, New York, and building corner Eighty-first street and Ninth avenue, New York.

Franklin County, Maine, Quarries.—The Maine and New Hampshire Granite Corporation quarries are at North Jay. The granite is of very light gray shade, "white granite," and of fine, even-grained texture. Specimen structures: General Grant's tomb, New York; Richard Smith Soldiers' and Sailors' Memorial gateway, Fairmount Park, Philadelphia; Chicago and Northwestern Railway building, Chicago; Western German Bank, Cincinnati; Union County Court House, Elizabeth, N. J.; Bowling Green building, New York; etc.

The American Stone Company's quarry also is at North Jay. The granite is identical with that of the preceding, and was used in all but the basement of Senator W. A. Clark's residence on Seventy-seventh street and Fifth avenue, New York.

Hancock County, Maine, Quarries.—Bluehill. Medium gray, coarse, even-grained; specimen buildings: Woman's Hospital, New York; Mercantile Trust Company's and Caledonia Insurance Company's buildings, St. Louis; part of extension to House of Representatives; part of District of Columbia municipal building; First Day and Night Bank, New York; Delamar and Brokaw residences, New York; chemical laboratory of Pratt Institute, Brooklyn, N. Y.; chemical laboratory of Stevens Institute of Technology, Hoboken, N. J.

Mount Desert. Light grayish buff, coarse even-grained; specimen buildings: United States Mint, Philadelphia; basement of the custom-house, New York; new bridge over the Potomac River, Washington. Light grayish pink; the Crocker residence, Darlington, N. J.; Danforth Library, Paterson, N. J.; First National Bank building, Baltimore, Md., Phoenix National Bank, Hartford, Conn.

Crotch Island. Lavender medium gray, coarse even-grained; specimen buildings: Post-office, Lowell, Mass.; court-house, Delham, Mass.; cadet armory, Boston, Mass.; Public Library, Laconia, N. H.; Ninth Regiment armory, New York; approaches to East River bridge, No. 3, New York; trimmings for University Heights bridge, New York.

Moose Island. Lavender medium gray, coarse, even-grained; specimen buildings: Gate-house at Central Park, and steps of Columbia University, New York; trimmings of Hampton Dormitory, Cambridge, Mass.

There are other quarries in Hancock County, in the towns of Bluehill, Brooksville, Delham, Franklin, Long Island, Mount Desert, Sedgwick, Stonington, Sullivan, Swans Island and Tremont, which have supplied granite for important structures.

Lincoln County, Maine, Quarries.—These quarries are in the towns of Bristol, Waldoboro and Whitefield.

The granite from the Waldoboro quarry is of a medium gray color, and of fine, even-grained texture. Specimen buildings: Buffalo, N. Y., Savings Bank; armory, boat-house and cadets' quarters, United States Naval Academy, Annapolis, Md.; Chemical National Bank, New York.

Oxford County, Maine, Quarries.—These quarries are in the towns of Fryeburg, Oxford and Woodstock. The color of the granite is medium gray and medium cream gray, and specimens of the material may be seen in the public library at Conway, N. H.; the Roman Catholic Church, Berlin, Me.; the McGillicuddy block, Lewiston, Me.; all bridges and stations of the Grand Trunk Railway.

Penobscot County, Maine, Quarries.—These quarries are in the town of Hermon, and produce a black granite, described as "an altered diabase porphyry of dark green color and fine texture, with porphyritic crystals of black hornblende up to three-fourths inch in diameter."

Piscataquis County has a quarry in the town of Guilford, producing a light gray granite.

Somerset County has quarries in the towns of Hartland and Norridgewock producing granite of medium and light gray color.

Waldo County, Maine, Quarries.—These quarries are in the town of Frankfort, Lincoln and Swanville. The color of these granites is medium and light gray, and also black and dark gray, that from Swanville being the darkest of the fine-textured granites of the State. The grays have been used in the post-office at Lynn, Mass., post-office, Chicago, Ill.; post-office, Milwaukee, Wis.; post-office, Indianapolis, Ind.; United States Mint, Philadelphia, Pa.

Washington County, Maine, Quarries.—These quarries are located in the towns of Addison, Baileyville, Calais, Jonesboro, Jonesport, Marshfield and Millbridge.

Addison and Baileyville quarries produce dark gray and black shades.

Calais quarries produce dark grays, blacks, dark reddish-greenish grays, dark reddish shades, bright pinkish shades, red shades and pink shades. The Maine Red Granite Company's granite works are in Calais, and include the most extensive plant for polishing granite in the State. Specimens of polished work are seen in the four fluted columns, 22 by 3 feet, of Shattuck Mountain red granite for the court-house at Marquette, Mich., and balusters of gray granite for the court-house at Kansas City, Mo. The Redbeach Granite Company's quarry, in the town of Calais, furnished the granite, of a bright pinkish color, for the two corner wings of the American Museum of Natural History, in New York.

The Bodwell-Jonesboro quarries furnished a grayish pink colored granite for the Bourse, Philadelphia; for the West End Trust Co.'s building, New York; for the custom-house and post-office at Buffalo, N. Y.; for the Methodist Book Concern building, and for the Havemeyer residence, New York; for the custom-house and post-office at Fall River, Mass.; for the town

buildings at Peabody, Mass., and for the Western Savings Bank building, Philadelphia.

The Jonesport quarries furnished a dark reddish gray granite for the Colorado building, Fourteenth and G streets, Washington, D. C.; State armory, Providence, R. I.; power-house of the Metropolitan Street Railway, Interurban, Ninety-fifth to Ninety-sixth streets and First avenue to East River, New York. These quarries also furnished the dark reddish gray granite, known commercially as "Moose-a-bec red," for the wainscoting and stairway in main entrance to Suffolk County court-house, Boston, Mass.; for the American Baptist Publication Society building, in Philadelphia, Pa., and 25 columns in the Roman Catholic Cathedral in Newark, N. J.

York County, Maine, Quarries.—These quarries are in the towns of Alfred, Berwick, Biddeford, Hollis, Kennebunkport and Wells, and produce granites of greenish dark gray, very dark olive brownish, light gray, medium gray pinkish buff, and light gray shades.

VERMONT.

Barre, Vt.—These granites are light and dark gray, clean, fine-grained stones, and may be had in almost any practicable size, free from all blemishes and defects.

Among other granites of importance may be mentioned those found in *Brunswick,* Essex County; *Morgan,* Orleans County; *Rycgate* and *St. Johnsbury,* Caledonia County; *Bethel,* Windsor County, and *Woodbury,* Washington county; and those at Windsor and West Dummerston.

Woodbury, Vt.—The granite from these quarries is a light gray, fine-grained stone, suitable for all kinds of buildings and constructive work. It was used in the following recently constructed buildings:

Public buildings: Pennsylvania State Capitol, Harrisburg, Pa.; Cook County court-house, Chicago, Ill.; Kentucky State Capitol, base-course and interior polished columns, Frankfort, Ky.; Iowa State Capitol, steps and platforms, Allentown Hospital, Allentown, Pa.; Syracuse, N. Y., University library; Syracuse, N. Y., University gymnasium; post-office, Providence, R. I.; post-office, Hamilton, Ohio; post-office, Des Moines, Iowa. Bank and office-buildings: Commonwealth Trust Co., Pittsburg, Pa.; Machesney building, Pittsburg, Pa.; Bank of Ohio Valley, Wheeling, W. Va.; Schmulbach building, Wheeling, W. Va.; Peoples' Savings Bank, Toledo, Ohio. Hotels: Hotel Knickerbocker, New York City; National Hotel, Rochester, N. Y.; Hotel Pontchartrain, Detroit, Mich. Monumental work: Archway at Port Huron, Mich.; Soldiers' and Sailors' monument, Scranton, Pa.; Confederate monument. Springfield, Mo. Miscellaneous: Northern avenue bridge, Boston, Mass.; Mortuary Chapel, Schenectady, N. Y.; crematory, Linden, N. J.

Bethel, Vt.—The granite from these quarries is a very choice and beautiful stone, ranking among the very whitest, and showing a very high compressive strength, running up to 33,150 pounds per square inch. It has been used in the following buildings:

Wisconsin State Capitol, Madison, Wis.; Title Guarantee and Trust Com-

pany building, 176 Broadway, New York City; Importers' and Traders' National Bank, 247 Broadway, New York City; Essex County court-house, base and approaches, Newark, N. J.; American Bank Note Company building, Broad and Beaver streets, New York City; Harry Payne Whitney residence, Seventy-ninth street and Fifth avenue, New York City; Union Station, in part, Washington, D. C.

Windsor, Vt.—At Windsor are operated quarries on Mount Ascutney, from which is produced a dark bronze green granite, used for polished columns and other work of similar character. This granite was used for the sixteen polished column shafts in the interior of the library building of Columbia University, New York. They are 24 feet 9½ inches long and 3 feet and 7 inches in diameter. It was used also for thirty-eight large columns for the office of the Bank of Montreal, Montreal, Canada.

West Dummerston, Vt.—The granite from these quarries come in shades of white and blue. It has been used in the Royal Baking Company's office-building, New York; for the interior columns in Cathedral, Newark, N. J.; in the Kellogg-Hubbard Library, Montpelier, Vt.; the Patten residence, Evanston, Ill.; Thames Loan and Trust Company's building, Norwich, Conn.; First National Bank building, Spring Grove, Pa.

MASSACHUSETTS.

Quincy, Mass.—The Quincy granite quarries are among the oldest in the country. The product is, as a rule, dark, blue-gray in color, coarse-grained and hard. Composition: quartz, hornblende and feldspar.

It has been used in many buildings, among which may be mentioned: The United States custom-houses at Boston, Providence, Mobile, Savannah, New Orleans and San Francisco; Masonic Temple and Ridgeway Library buildings, and polished stairways and pilasters of the city-hall, Philadelphia.

Gloucester, Cape Ann; and *Rockport, Peabody, Wyoma, Lynn* and *Lynnfield, Mass.*—These quarries produce hornblende granites, of a gray or greenish color. The material was used in the post-office and in several churches and private buildings in Boston, Mass., and in the Butler house on Capital Hill at Washington, D. C.; in the towers and superstructure work for the new Cambridge Bridge between Boston and Cambridge, Mass.; in Blackwell's Island Bridge, New York, Manhattan and Queens approaches, and in the Registry of Deeds and Probate court-house at Salem, Mass.

Milford, Brockton, North Easton, Mass.—These quarries produce granites of mellow tints of light creamy pink, with lively black spots. Among specimen buildings in which they were used, may be mentioned the following: Allegheny County court-house and jail, Allegheny, Pa.; Chamber of Commerce buildings in Boston, Mass., and Cincinnati, Ohio; the polished columns of the Madison Square Garden and of the New York Herald building in New York; city-hall, Worcester, Mass.; University Club, New York; Union Railroad station, Albany, N. Y.; Pennsylvania Railroad terminal station, New York; Public Library building, Boston, Mass.; John Hancock Mutual Life Insurance Co.'s building, Boston, Mass.; Pennsylvania building, Phila-

delphia, Pa.; Hanover National Bank building, New York; Columbia University Library building, New York; New York Insurance Company's building, New York, and Continental National Bank building, Chicago, Ill. A polished sphere, five feet in diameter, of this granite surmounts the column of Stony Creek, Conn., reddish granite, in the battle monument at West Point, N. Y.

Framingham, Leominster, Fitchburg, Clinton, Fall River and Freetown, Mass.—These quarries produce coarse gray, strong and durable granites.

Dedham, Mass.—Fine-grained, light pink granites from these quarries were used in Trinity Church building, Boston, Mass.

Westford, West Andover, Lawrence, Lowell, Ayer, Becket, Northfield, Monson and towns in *Worcester County, Mass.*—These quarries produce fine-grained very light gray, sometimes pinkish gneiss of good quality. Among specimen buildings in which the material from the Monson quarries was used may be mentioned the following: Hall of Records, Springfield, Mass.; St. Francis Xavier's Church, New York; St. Leonard's Church, Brooklyn, N. Y., and monastery at Hunt's Point, N. Y.

CONNECTICUT.

Roxbury and *Thomaston,* Litchfield County; on *Long Island Sound,* Fairfield County; *Ansonia, Bradford, Leetes Island,* and *Stony Creek,* New Haven County; *Haddam,* Middlesex County, and *Lyme, Niantic, Groton* and *Mason's Island,* New London County, Conn.—At all of these places there are located extensive quarries of granite and gneiss, which are generally fine-grained in texture and light gray in color.

Stony Creek, Conn.—These granites are known also as "Branford Granites," the quarries being located in Stony Creek, in the township of Branford, Conn. These were opened and developed by Norcross Brothers in 1887, and contain practically inexhaustible deposits of reddish colored stone, well adapted for constructive, decorative or ornamental work. Some of the more important work in which this granite has been used is as follows: South Terminal station, Boston, Mass.; Exchange building, Boston, Mass.; in several buildings at Columbia University, New York; Connecticut River Bridge, Hartford, Conn.; St. Gaudens' equestrian statue of General Sherman at entrance to Central Park, New York; the polished column for the battle monument at West Point, N. Y., a monolithic shaft, 41½ feet long by 6 feet in diameter; the monument commemorating the fiftieth anniversary of the opening of the canal at Sault Ste. Marie, Mich., a shaft 4 feet 5 inches square at the base and 45 feet long; Broadway Chambers, New York; New York Central post-office and office-building, Lexington avenue, New York; Bellevue Hospital, New York, and the McKinley monument, near the city-hall, Philadelphia, Pa.

Waterford, Conn.—The quarries at this place produce granites of fine white texture and of a light color, well suited to work of a monumental character. Recent work in which this stone is used is represented by the sculptured monument to the soldiers and sailors in the town of Northbridge,

Mass., at Whitinsville; and the Williamsburg and Greenpoint Savings Bank, New York.

NEW HAMPSHIRE.

Concord, N. H.—A fine-grained granite, light gray in color, with a silver lustre; well-developed rift and grain, and remarkable for the ease with which it can be worked. Constituents: opaque quartz, soda-feldspar and white mica. Well adapted for statuary and monumental purposes, as well as for general building. The stone is eminently durable, the New Hampshire State House, built of this stone in 1816-19, being still in an excellent state of preservation.

From the list of specimen buildings in which granite from the Concord quarries was used may be mentioned the following: Congressional Library and new Senate office building, Washington, D. C.; Union Trust building, Pittsburg, Pa.; Camden County court-house, Camden, N. J.; Tradesman Trust Company's building and Alta Friendly Society's building, Philadelphia, Pa.; Standard Oil Company's building, Western National Bank building, First Church of Christ Scientist, New York; and Blackstone Library building, Chicago, Ill.

Marlboro and Fitzwilliam, N. H.—These quarries produce light gray, fine, close-grained granites, and the following is a list of some of the important buildings in which they have been used: Clark University buildings, and residence of Jonas G. Clark, Worcester, Mass.; First Church of Christ Scientist, Somerset hotel, and Buckminster Chambers, Boston, Mass.; Vanderbilt Memorial Hospital building, Newport, R. I.; city-hall, Newark, N. J.; Industrial Trust Company's building, Pawtucket, R. I.; Marshall Field building, Chicago, Ill.; and armory for the Lawrence Light Guard, Medford, Mass.

Troy, N. H.—These quarries produce a fine-grained gray granite, of pronounced whitish effect after it is cut. Specimen structures in which it has been used are: Cathedral of the Sacred Heart, Newark, N. J.; Pittsburg Bank building, Pittsburg, Pa.; the approaches to the Library of Congress, Washington, D. C.; and the Hanna mausoleum, Cleveland, Ohio.

Redstone, N. H.—The two quarries at this place are adjacent, yet distinct. One produces granite of a warm pink shade, the other a granite of a mottled green color. The following are specimen buildings in which the pink granite was used: Russia stores, Boston and Maine union station, Boston, Mass.; Leiter block, W. C. T. U. temple, Michael Reese Hospital, Chicago, Ill.; Brooklyn Real Estate Exchange, power station, 59th street, Franklin Savings Bank, New York; Fidelity Mutual Life Association building, Philadelphia, Pa.; Todd building, Louisville, Ky.; Cleveland Chamber of Commerce, Cleveland, Ohio; First and Fourth National Bank buildings, Cincinnati, Ohio; Equitable Insurance Company's building, Des Moines, Ia.; Memphis Trust Company's building, Memphis, Tenn.; Bank of British North America, Winnipeg, Canada; Richardson and Tuck Halls, Dartmouth College, Hanover, N. H.; Erie Public Library, Erie, Pa.; State Library, Concord, N. H.; and Memorial Library, Lowell, Mass.

Specimen buildings in which the green granite was used are: Northwestern Guaranty Loan building, Minneapolis, Minn.; J. P. Maginnis' residence, Chicago, Ill.; Portland Savings Bank building, Portland, Me.; and building at 777 Broadway, New York.

RHODE ISLAND.

Westerly, R. I.—Granite of fine grain and even texture and of excellent quality. Constituents: quartz, feldspar and mica, with some hornblende. Color, rich light gray or pink, with a distinct tint of brown when polished.

Among the specimen buildings in which the Westerly, R. I., "red granites" have been used are the following: American Tract Society buildings, Washington Life Insurance Company's building, American Exchange Bank building, New York; Travelers' Insurance Company's building, Hartford, Conn.; Colonial Trust Company's building and Arrott building, Pittsburg, Pa.

NORTH CAROLINA.

The granites of North Carolina are distributed over about one-half the total area of the State, but the productive part of the area is considerably less. Openings from which more or less granite has been quarried in the past have been made in the majority of the counties in which granites occur, but in 1906 less than a dozen quarries were being systematically worked. The prevailing color is light gray, with a pinkish cast, and there are also delicate shades. From the quarries at Granite Quarry in Rowan County come the Belfour pink granites, especially superior stones for statuary and finely carved work, for mausoleums and monuments. Neighboring quarries produce also a gray granite which is similar in all its properties to the pink, except in color. These granites are of uniform color and texture and take an exceptionally high polish.

For very complete and reliable data on the subject the reader is referred to "The Building and Ornamental Stones of North Carolina," by Thomas L. Watson and Francis B. Laney, with the collaboration of George P. Merrill, Bulletin No. 2, of the North Carolina Geological Survey. Raleigh, N. C., 1906.

GEORGIA.

The granites of Georgia are distributed over all of the State north of a line drawn from Augusta, through Macon to Columbus, with the exception of the extreme northwestern portion of the State. Of this section granites and gneisses have been quarried only in those counties comprised within the limits of what is known as the "Piedmont Plateau." Up to 1902 less than a score of these counties included the entire granite industry in Georgia; but recently quarry developments have been rapid. The State has enormous quantities of superior stone. The prevailing colors are light gray, dark gray and dark blue-gray.

In DeKalb County are situated the Stone Mountain, Pine Mountain and Arabia Mountain granite quarries. The Stone Mountain granite was used in the following buildings taken from a larger list: United States post-office, Wheeling, W. Va.; court-house and city-hall, New Orleans, La.;

terminal station, New Orleans, La.; Fulton County court-house annex and Fulton County jail, North Avenue Presbyterian Church, First Methodist Church, First Baptist Church, and St. Mark's Methodist Church, United States Federal prison, and the United States post-office building, Atlanta, Ga.

For extended data the reader is referred to "A Preliminary Report on a Part of the Granites and Gneisses of Georgia," by Thomas L. Watson, Assistant Geologist, Bulletin No. 9—A, of the Geological Survey of Georgia, Altanta, Ga., 1907.

MISSOURI.

The major part of the granite works of Missouri are in an area of about 110 to 120 square miles, and confined to nine counties in the southeastern part of the State. In color the granite varies from light gray through different shades of reddish pink to brownish red.

The stone has been used in many important buildings in St. Louis, Kansas City, Chicago and other cities.

For further recent detailed data the reader is referred to "The Quarrying Industry of Missouri," by E. R. Buckley and H. A. Buehler, Vol. II, 2d Series, Missouri Bureau of Geology and Mines, Jefferson City, Mo., 1904.

WISCONSIN.

The following are the areas from which granites have been quarried during the past few years: Montello, Berlin, Waushara, Utley, Marquette, Granite City, Waupaca, Wausan and Amberg, and situated generally in the north-central part of the State. The quarries furnish granites of colors varying from brilliant red to dark gray.

From the Montello quarries, situated in the central part of Marquette County, come the dense, fine-grained, uniform bright red and grayish granites. They rank among the most durable granites, though necessarily difficult to cut and to dress. It was from these that the stone was selected for the sarcophagi for General and Mrs. Grant at Riverside Park, New York. These granites were used also in the McKinley monument at Canton, Ohio.

For further detailed data the reader is referred to "The Building and Ornamental Stones of Wisconsin," by Ernest R. Buckley, Assistant Geologist, Wisconsin Geological and Natural History Survey, Bulletin No. IV, Madison, Wis., 1908.

OTHER STATES AND SECTIONS.

Maryland.—Maryland granites are better adapted to general constructional work than to monumental purposes, and are light to dark gray in color, and medium fine-grained in texture.

New Jersey.—But few granite quarries have been opened, yielding mostly gneiss, used almost exclusively for heavy construction work.

New York.—Notwithstanding the reported recurrence of gneisses and granites, suitable for general economic purposes, over various portions of the eastern and northeastern sections of the State, the granite industry of the State of New York is comparatively small.

From the quarries situated on the north end of Picton Island, three miles from Clayton, N. Y., comes the medium-grained granite called "Picton Island

Red Granite." It is a bright and handsome stone, well suited to building purposes, and adapted to taking a high polish. Among the buildings in which it has been used may be mentioned the American Museum of Natural History, New York, and 25 decorative polished columns in the Maryland Institute building in Baltimore, Md.

Pennsylvania.—This State furnishes nothing in the way of granite rocks to the markets, outside of its own limits. The granitic stone quarried is gneiss, with the quarries grouped and in close proximity to Philadelphia.

Delaware.—The production of granite rocks in Delaware is very limited, the only locality where quarries have been opened being near Wilmington. The rock is a dark gray augite-hornblende gneiss, used for general building purposes.

South Carolina.—A fine and even-textured, gray biotite granite, of excellent quality, is quarried near Winnsboro, Fairfield County, and a granite of slightly pinkish hue occurs in the same county. Granite is found in six other counties also.

Tennessee.—Scarcely anything in the line of granite rock is quarried in this State.

Virginia.—The principal quarries are located near Richmond and Petersburg, those near Richmond having produced a large supply of stone, marketed in all States south of New England. The War, State and Navy building in Washington, D. C., was constructed of the Virginia granite. The Virginia granites are generally medium coarse-grained and light gray in color, and are said to correspond very closely to those of New England.

Minnesota.—The granites of this State are very similar to those of Wisconsin. They are excellent granites of the gray and red, fine and coarse-grained varieties, carrying hornblende and biotite as the chief accessory minerals. At St. Cloud, Minn., both gray and red granites are quarried, the latter greatly resembling the Scotch granite in color, grain and polish. The gray granite is about one-third quartz and two-thirds feldspar.

Western States.—The granites of the Western States have been only sparingly quarried. While the rock abounds in both quantity and quality throughout various portions of the West, quarrying is limited almost exclusively to California, Colorado, South Dakota, Montana and Oregon; and it is carried on sparingly in Utah, Idaho, Nevada, Washington and Wyoming. The granites of this section of the country range in color from light gray to red, and in texture from fine to coarse grain.

In Colorado the principal quarry is at Gunnison, which produces a blue-gray granite, which may be seen in the Colorado State House.

3. LIMESTONES.

231. GENERAL DESCRIPTION.—This name is commonly used to include all stones which contain lime, though differing from each other in color, texture, structure and origin. All limestones used for building purposes contain one or more of the fol-

lowing substances, in addition to lime: Carbonate of magnesia, iron, silica, clay, bituminous matter, mica, talc and hornblende.

There are three varieties of limestone used for building purposes, viz.: *Oolitic limestone, magnesian limestone* and *dolomite.*

Oolitic limestones are made up of small rounded grains resembling the eggs of a fish, that have been cemented together with lime to form solid rocks.

Magnesian limestones include those limestones which contain 10 per cent or more of carbonate of magnesia.

Dolomites are crystalline granular aggregations of the mineral dolomite, and are usually whitish or yellowish in color. They are generally heavier and harder than limestones.

Almost all varieties of limestone contain more or less pulverized shells, corals and fossils of marine animals. A limestone can be identified by its effervescence when treated with a dilute acid.

Many of the finest building stones are limestones, but as they are less easily and accurately worked than sandstones they are not so largely used as the latter, except in the localities where the best varieties are found.

The color of limestone is generally light gray, sometimes deep blue, and occasionally cream or buff. The light gray varieties often resemble the light, fine-grained granites in general appearance.

Most of the granular limestones take a high polish.

Good limestone should have a fine grain and weigh about 145 pounds per cubic foot.

Many of the limestones described below are very durable, but the light-colored stones are apt to become badly stained in large cities, especially where soft coal is used.

All kinds of limestone are destroyed by fire, although some varieties will stand a greater degree of heat without injury than others.

232. DESCRIPTION OF SOME IMPORTANT LIMESTONES.—The limestones most extensively used for building purposes come from the States of Illinois, Indiana, Ohio, New York and Kentucky.

The most celebrated American limestone is that quarried at *Bedford, Indiana.* It is a light-colored oolite, consisting of shells and fragments of shells so minute as to be scarcely discernible to the naked eye and cemented together by carbonate of lime.

This stone is most remarkably uniform in grain and texture, is exceedingly bright and handsome in color, and is less liable to discolor than most light stones.

It has about the same strength in vertical, diagonal and horizontal directions, and when first quarried is so soft that it can be easily worked with saw or chisel. It hardens, however, on exposure, and attains a compressive strength of from 10,000 to 12,000 pounds per square inch. Owing to its fine and even grain and to the ease with which it can be cut in any direction, it is especially suitable for fine carving and is also very durable.

On account of its many excellent qualities it was selected by the architect for Mr. George W. Vanderbilt's palatial residence at Biltmore, N. C. It was also used in the following buildings: The Auditorium building, Chicago; the Manhattan Life Co.'s building, New York; the mansion of Mr. C. J. Vanderbilt on Fifth avenue, New York; the State Capitols at Indianapolis, Ind., Jackson, Miss., Frankfort, Ky., and Atlanta, Ga.; Walters art gallery, Baltimore, Md.; Public Library and Museum building, Milwaukee, Wis.; State Historical building, Madison, Wis.; court-house, Huntington, Ind.; Catholic Cathedral, Pittsburg, Pa.; Trinity building and Boreel annex, New York City, N. Y.; Federal building, Indianapolis, Ind.; St. Paul's Cathedral, Pittsburg, Pa.; all the buildings for the University of Chicago, Chicago, Ill.; main art palace, World's Fair, St. Louis, Mo.; First National Bank, San Francisco, Cal.; all buildings for the University of Iowa, both at Iowa City and Ames, Iowa; Union Club, New York City, N. Y.; Yacht Club, New York City, N. Y.; the Handley Library at Winchester, Va. In the residence of E. G. Fabri, New York City, Bedford stone was used for both exterior and interior work.

Bedford stone is of the same geological age as the famous Portland stone of England, out of which St. Paul's Cathedral of London is constructed. Below is given a comparative analysis:

	Portland Stone.	Bedford Stone.
Carbonate of Lime	95.16	97.26
Silica	1.20	1.69
Oxide of Iron	.50	.49
Magnesia	1.20	.37
Water and loss	1.94	.19
	100.00	100.00

Regarding the crushing strength, a test made by the United States Government gives the crushing strength of Bedford stone at about 135,000 pounds per square foot. That this enables it to sustain an enormous weight is shown by the following table of maximum weights borne by the piers and masonry of some well-known structures:

	Pounds per sq. foot.
Piers of St. Peter's Rome	33,000
Piers of St. Paul's, London	39,000
Piers of Brooklyn Bridge	57,000
Granite Masonry of Washington Monument	45,000
Reliable sustaining weight of Bedford stone	135,000

Indiana limestone, or Bedford stone, is not as porous as Portland stone, the English product. It is more easily worked, responding readily to mallet and tool in the hands of workmen, and it can also be planed or turned by machinery, which advantage adds to its desirability, as it minimizes the cost of preparing it.

The oolitic belt of Indiana extends over a portion of the counties of Lawrence and Monroe, and is about thirty miles in length and about six miles in width. It is a homogeneous limestone, the upper ledges of which are light buff in color. At a depth of about 30 feet the stone in most places changes abruptly to a decided blue shade. The texture and other chemical properties remain the same from the point where the color changes to a depth of about 30 feet more, at which point the stone becomes very coarse, and seems to be of a shelly formation.

Alabama has a dark compact limestone, some of it closely resembling the Bedford, Indiana, stone.

Arkansas produces a durable, oolitic limestone suitable for building, and also a cream-colored magnesium limestone of good quality.

Colorado furnishes a coarse, reddish limestone, and also a compact, finely crystalline black stone.

In *Florida* there is a loose and porous oolitic limestone at Key West, and the coarse, porous shell limestone called "Coquina" quarried at Anastasia Island.

In *Illinois* almost the entire building stone product is limestone or dolomite, with a few sandstone quarries. The most notable of the limestones is the fine-grained, very light colored Niagara stone from near Lemont and Joliet. There are many other localities in the State which furnish excellent varieties of building stone.

There are large quarries of limestone also at Grafton and Chester, and from the quarries at East Fort Madison, Hancock County, Ill., come the "Appanoose Dolomite Stone," a strong and durable stone.

Iowa abounds in limestones and dolomites, which, however, so far enjoy only a local reputation. There are numerous small quarries, producing, however, many good building stones.

Kansas has limestones and dolomites of generally light color, and of soft and porous texture, although there are some exceptions, several varieties having a firm and compact texture and acquiring a good surface and finish.

There are large quarries of limestone in the vicinity of Topeka. This stone can be worked almost as easily as wood, and yet becomes hard and durable when placed in a building. There are also several small quarries which supply the local demand in various parts of the State.

Kentucky has limestones of the finest quality and in inexhaustible quantities, the oolitic limestones being without superiors, if indeed they have equals. But these building stones are almost unknown in the principal markets, and such as are quarried have only a local reputation.

The best known of the Kentucky limestones is probably the Bowling Green oolitic stone quarried at Memphis Junction. This stone is almost identical in composition with the celebrated "Portland" stone of Great Brit-

ain. Its color is light gray. It is as readily worked as the Bedford stone, is very durable, and is pre-eminent in its resistance to the discoloring influences of mortar, cement and soil.

The "Green River Stone" comes from the quarries at Hadley, Warren County, Ky., which produce a stone dark in color when first quarried, but bleaching out white upon exposure to the weather. The stone is similar to the Bedford stone, being a close-grained oolitic limestone. It was used in the Pennsylvania State Library building, Harrisburg, Pa., the residence of S. B. Elkins, Philadelphia, Pa., and the Daviess Company Bank building, Owensboro, Ky.

Maine has little if any limestone that is well adapted for building stone, as it is generally blue or blue-black, veined with white, a combination thought to be not desirable.

Michigan has limestones and dolomites suitable for building stones, but they have been but comparatively little quarried.

Minnesota furnishes limestones and dolomites generally of a light buff, drab or blue color, fine-grained and compact.

Missouri's limestones and sandstones from all formations have been used to some extent in buildings. A majority of the quarries in the sedimentary formations are engaged exclusively in producing stone to supply the local market.

At Carthage, Jasper County, Missouri, there are extensive quarries of limestone, which produce large quantities of both quicklime and building stone. The stone is coarse-grained and crystalline, takes a good polish, and is well adapted to exterior finishing.

Excellent quarries of limestone exist also at Phœnix, Missouri, the stone being shipped to St. Louis, Kansas City and Omaha.

Nebraska has carboniferous limestones in several counties of such quality as to render them suitable for building purposes; but few if any of them are in demand outside the limits of the State.

New York has several limestones belonging to seven or eight different geological formations. A gray limestone is quarried at Lockport and Rochester, N. Y., which is extensively used for trimmings in that State and in some parts of New England. The limits of this chapter will not permit any consideration of these several building stones, and the reader is referred to the various publications bearing upon the stones of New York State.

North Carolina.—On account of the lack of a large enough market and of transportation facilities, the limestones and dolomites, although of very good quality for building purposes, are not extensively quarried.

Ohio.—The limestones and dolomites of Ohio, while in many instances used locally for building purposes, are employed chiefly for rough foundation work, street paving and flagging and for making quicklime. This is because they are generally of a dull and uninteresting color, and not well suited for any kind of fine building or ornamental work, although often strong and durable. There are large quarries of limestone at Dayton and Sandusky.

Pennsylvania.—Formations in Montgomery, Lancaster and Chester Counties furnish gray or bluish gray limestone, used for general building. Other localities furnish calcareous dolomites, limestone, breccias, etc., none of which possesses such characteristics as would make it of more than local value. From the Avondale, Chester County, Pa., quarries comes the "Avondale Limestone," varying in color from white to light brownish gray. It has been used in many churches and other buildings in Philadelphia, Pa., and in buildings in neighboring cities and towns.

Tennessee.—None of the limestones are quarried for anything more than local use.

Texas.—Near Austin, and also in Burnett County, are respectively found light-colored, fine-grained limestones, and dark mottled limestones; and near San Saba, compact, fine-grained cretaceous limestones of poor quality.

Wisconsin.—A large part of the State is immediately underlain by limestone, the suitability of which for building purposes is widely different, in different localities. The colors range from buff or straw yellow to dark bluish gray. In some parts of the State the limestone is closely compacted and crystalline, often resembling marble. In other places it has a loose, open texture. Bridgeport, Trempealeau and Maiden Rock furnish magnesian limestone suitable for all ordinary purposes. The Trenton formation, on which many of the important cities of the State are located, furnishes a blue limestone extensively used locally for buildings. It has proven satisfactory where there is no danger from freezing. At Watwatosa, Lannan, Genesee, Marblehead, Sturgeon Bay and Knowles there is a good limestone generally suited to building purposes.

4. MARBLES.

233. GENERAL DESCRIPTION.—Marble is simply a crystallized limestone, capable of taking a good polish.

The scarcity and constant expense of good marbles have in the past prevented them from being used in constructional work, except occasionally for columns. Most of the marbles obtained from the older quarries also stain so easily that they are considered undesirable for exterior work.

Since the rapid development of the Georgia and Tennessee quarries, however, the marbles taken from them have been much used for exterior finish, and even for the entire facing of the walls. They will probably be more extensively used for exterior work in the future, as they are exceedingly strong and durable and do not readily stain.

Nearly all varieties of marble are worked with comparative ease, and the fine-grained varieties are especially adapted to fine carving. They generally resist frost and moisture well, they are admirably

suited for interior decoration, sanitary purposes, etc., and in clear, dry climates make splendid material for exterior construction.

The compressive strength of marble varies from 5,000 to 20,000 pounds per square inch, but it is only when used for columns that this strength need be considered.

For the composition and strength of various marbles see the tables in the Appendix.

234. PRODUCTION OF MARBLE IN THE UNITED STATES.—The marble output in the United States in 1906 was valued at $7,582,938.

Vermont produces the greater part of the marble of the United States, the output of this State representing 60.36 per cent of the total output of the country in 1906, and amounting to about 1,400,000 cubic feet.

In that year Georgia ranked second in the marble-producing States, its value of output representing 12.12 per cent of the total of the United States, and amounting to 875,000 cubic feet.

TABLE XXII.

DISTRIBUTION AND VALUE OF OUTPUT OF MARBLE, 1902-1906, FOR VARIOUS USES.

Use	1902	1903	1904	1905	1906
Sold by producers in rough state	$2,275,429	$2,454,263	$2,599,052	$2,987,542	$1,795,169
Dressed for building	1,038,302	1,111,072	988,671	1,168,450	1,559,925
Ornamental purposes	7,300	51,359	21,554	13,643	44,523
Dressed for monumental work	956,870	1,062,339	1,211,389	1,170,279	2,214,872
Interior decoration in buildings	679,913	663,553	1,257,963	1,682,651	1,722,445
Other uses	86,368	20,100	219,206	106,506	246,004
Total	$5,044,182	$5,362,686	$6,297,835	$7,129,071	$7,582,938

In 1906 the next States and territories in order of output were Tennessee, New York, Massachusetts, Maryland, Pennsylvania, California, Alabama, Washington, Arkansas, Nevada, Utah, Wyoming, New Mexico, Missouri and Alaska.

In Pennsylvania's output is generally included a production of serpentine from Northampton county, and small quantities of serpentine are also generally included in the Georgia outputs.

The outputs of California, New Mexico, Utah and Wyoming often include small quantities of onyx.

The greater part of the marble output is for building and monumental work, the values for the two being nearly equal in 1906.

Table XXII shows the various uses to which the marble quarried in 1902, 1903, 1904, 1905 and 1906 was put.

From this table it appears that while the rough marble sold to manufacturers, dealers and contractors decreased in value, the dressed stone of all kinds sold by the quarrymen increased.

235. DESCRIPTION OF SOME IMPORTANT AMERICAN MARBLES.—Great quantities of white and black marble are quarried in this country, but nearly all of the beautiful streaked and colored marbles are imported.

Vermont Marble.—This State is the greatest producer of marble of any State in the Union, the total product in 1906 amounting to $4,576,913, more than the combined value of all other marbles quarried in the country.

The largest quarries are at West Rutland and Proctor.

Among other towns in which the marble quarrying industry has been particularly active may be mentioned Dorset, East Dorset, Wallingford, Pittsford, Brandon and Middlebury.

In texture Vermont marble is, as a rule, fine-grained, although some of it is coarse-grained and friable. In color it varies from pure snowy white through all gradations of bluish, and sometimes greenish shades, often beautifully mottled and veined, to deep blue-black, the bluish and dark varieties being, as a rule, the finest and most durable.

These marbles are used principally for monumental and statuary work, and for decorative work, sanitary fittings, tiling, etc., in buildings.

At Proctor the stone is very massive, and large blocks are taken out for general building purposes.

Vermont marble has been used for the exterior and interior of innumerable buildings. Merely as illustrations the following specimen buildings in which it has been used may be mentioned: Church of our Lady of Good Council, East 9th street, and Church of the Ascension, 107th street, New York; United States post-office and court-house, Worcester, Mass.; water tower, Fort Ethan Allen, Essex, Vt.; Hart Memorial Library, Troy, N. Y.; Clio Hall, Princeton College, Princeton, N. J.; Metropolitan Club, New York; Second National Bank building, Paterson, N. J.; Knickerbocker Trust Company's buildings and Engineers' Club, New York; United States post-office building, Waterloo, Iowa; court of new Federal building, Cleveland, Ohio; public library, Atlantic City, N. J.; Tufts College Library building.

Georgia.—This State contains extensive beds of marble, which of late years have come into very general use. The quarries, which are situated in the northern part of the State, produce: 1st. A clear white marble, bright and sparkling with crystals. 2d. A marble with a dark mottled white ground, with dark blue mottlings; and also one with a light blue and gray ground, with dark mottlings. 3d. A white marble, with dark blue spots and clouds, and a bluish-gray marble, with dark spots and clouds. 4th. Pink, rose-tinted and green marbles in several shades. The appearance of the Georgia marbles is quite different from that of the marbles from the other States.

The stone is an almost pure carbonate of lime, free from foreign or hurtful ingredients. It is remarkably non-absorbent, and absolutely impervious to liquids, including even ink; and it is not subject to discoloration, atmospheric changes or decay. If soiled by dust or smoke it can be easily cleaned by washing with clean water alone, so as to look as bright as when first finished.

Georgia marble has been extensively used for monuments and for the interior finish of buildings, notably in the Congressional Library building at Washington, D. C. It is also used more and more every year for exterior construction, either for trimmings or for the entire walls. It may be seen on the exterior of the following buildings, given as illustrations: St. Luke's Hospital building, New York; post-office, Tampa, Fla.; Century building, St. Louis, Mo.; Bank of Montreal, Winnipeg, Canada; Equitable building, Atlanta, Ga.

It may be seen on the exterior and interior of the following: Girard Trust and Banking Company, Philadelphia, Pa.; Royal Bank of Canada, Montreal, Canada; Century building, Atlanta, Ga.

It may be seen in the interior of the following: Terminal station, Atlanta, Ga.; Kentucky State Capitol building, Frankfort, Ky.; Wilson building, Dallas, Texas; House of Representatives office-building, Washington, D. C.; court-house, Mendon, Neb.; Marion hotel, Little Rock, Ark.; Patten hotel, Chattanooga, Tenn.

Tennessee.—Marble has been quarried in this State since 1838, the principal quarries being in the vicinity of Knoxville, in East Tennessee. The varieties of marble produced from these quarries include grays, light pinks, dark pinks, buffs, chocolate and drabs. Only the pinks and the grays, however, are suitable for general building purposes, the darker colors being confined principally to furniture and interior work. The stone is 98 per cent carbonate of lime. The pink and gray varieties are well adapted to building purposes, their density and resistance to crushing being equal to that of any other marbles in the world.

They also offer great resistance to moisture, and are practically impervious to the staining or discoloring agencies of the atmosphere, except, perhaps, those which are found in large manufacturing centers. Under favorable conditions there appears to be no reason why they should not last for ages on the exterior of buildings. The highly colored varieties are among the handsomest produced in this country.

New York.—There are several quarries of gray, blue and white marble just north of New York City which furnish good building marble, but not quite good enough for decorative work. Much of it has been used for building purposes in New York City, and the best yet obtained from this series of deposits are those of Tuckahoe and Pleasantville in Westchester County.

At Gouverneur, in St. Lawrence County, there is a very coarsely crystalline light gray magnesian limestone, which, while too coarse for carved work, answers well for massive structures, and acquires a good surface and polish.

In Clinton County are found excellent fine-grained colored marbles of gray and gray-and-pink shades, known as "Lepanto" and "French Gray," and very extensively used for general interior work.

The best quality of black marble is quarried at Glens Falls, on the Hudson River.

Massachusetts.—In Berkshire County are medium fine-grained white or gray marbles used for general building. At Egremont are coarsely crystalline white and gray limestones from which were obtained the large Corinthian columns of Girard College, Philadelphia. From the Lee quarries came the marble used in the Capitol extension in Washington, D. C., and in the city buildings in Philadelphia.

Pennsylvania.—In this State are several quarries of a granular white and mottled marble, which have furnished a great deal of this stone for Philadelphia buildings.

Maryland.—Baltimore County is the important marble-producing center of the State, and contains the white stone of the Beaver Dam quarries, from which the 26-foot monoliths used in 1859-61 in the National Capitol were obtained. Nearby are the coarsely crystalline white limestones from which the material was obtained for the lower 150 feet of the Washington monument, in Washington, D. C.

Colorado.—This State contains beautiful varieties of marble, which it is thought in time may take the place of much of the foreign marble now imported. At present only a few quarries are worked. In Gunnison County, on the Yule Creek and Crystal River, there is a belt of white marble apparently superior in quality to anything found elsewhere in the United States. This marble belt is about 100 feet in thickness and not less than six miles in length. The prevailing colors are pure white, creamy white, and white slightly clouded with gray.

Other States and Territories.—The other States and territories mentioned in Article 234 have valuable marbles which are quarried in smaller and various quantities, and used for rough and dressed work, for general building purposes, for monumental and ornamental work and for interior decoration.

236. ONYX MARBLE.—The composition of these stones is the same as that of the common marbles, but they were formed by chemical deposits instead of in sedimentary beds crystallized by the action of heat. "They owe their banded structure and variegated colors to the intermittent character of the deposition and the presence or absence of various impurities, mainly metallic oxides. The term onyx as commonly applied is a misnomer, and has been given merely because in their banded appearance they somewhat resemble the true onyx, which is a variety of agate."

Owing to their translucency, delicacy and variety of colors, and to the readiness with which they can be worked and polished, the onyx marbles are considered the handsomest of all building stones, and they bring the highest price also; the cost per square foot for

slabs 1 inch thick varying from $2.50 to $6. Their use is confined to interior decoration, such as wainscoting, mantels, lavatories, and to small columns, table tops, etc. Most of the onyx marble used in the United States is imported from Mexico, although considerable onyx is quarried at San Luis Obispo, California; and quarries of very beautiful stone have recently been opened near Prescott, Arizona. The Mexican onyx presents a great variety of colors, such as creamy white, amber-yellow and light green, each generally more or less streaked or blotched with green or red. Some of the light stones have beautiful translucent clouded effects. When cut across the grain the stone often presents a beautifully banded structure like the grain of wood. Cutting the stone across the grain, however, reduces its strength greatly, so that it is necessary to back it with slabs of some stronger marble.

The San Luis Obispo stone is nearly white, finely banded and translucent, and it takes a beautiful surface and polish.

The Arizona stone presents a greater variety of coloring, ranging from milky white to red, green, old gold and brown, the colors intermingled in every possible way. Up to the present time a comparatively small amount of this stone is on the market, but farther developments will probably result in the production of large quantities of it.

5. SANDSTONES.

237. GENERAL DESCRIPTION.—"Sandstones are composed of rounded and angular grains of sand so cemented and compacted together as to form a solid rock. The cementing material may be silica, carbonate of lime, an iron oxide or clayey matter."

They include some of the most beautiful and durable stones for exterior construction; and on account of the ease with which they can be worked, and because of their wide distribution throughout the country, they are used more extensively than any other stones for exteriors.

The grains of sand themselves are nearly the same in all sandstones, being generally pure quartz; the character of the stone depends principally upon the cementing material. If the latter is composed entirely of silica, the rock is light-colored and generally very hard and difficult to work. When the grains have been cemented together by fusion or by the deposition of silica between the granules, and the whole hardened under pressure, the rock is

almost the same as pure quartz and is called *quartzite,* one of the strongest and most durable of rocks. "If the cementing material is composed largely of iron oxides the stone is red or brownish in color and usually not too hard to work readily. When the cementing material is carbonate of lime the stone is light-colored or gray, soft and easy to work." Such stones do not as a rule weather well, as the cementing material becomes dissolved by the rain, thereby causing a loosening of the grains and allowing the stones to disintegrate. Clay is still more objectionable than lime as a cementing material, as it readily absorbs water and renders the stones liable to injury by frost.

In several sandstones some of the grains consist of feldspar and mica, which have a tendency to decrease the strength.

Sandstones have a great variety of colors; brown, red, pink, gray, buff, drab or blue, in varying shades, being common varieties. The color is due largely to the iron in the composition. The *oxides* of iron do no harm, but no light-colored sandstone should be used for exterior work which contains *iron pyrites,* or sulphate of iron, as it is almost sure to cause stain or rust.

Sandstones vary in texture from almost impalpable fine-grained stones to those in which the grains are like coarse sand. All other conditions being the same, the fine-grained stones are the strongest and most durable and take the sharpest edge. Sandstones being of a sedimentary formation, are often laminated, or formed in layers; and if they set "on edge," or with the natural bed or surface parallel to the face of a wall, their outside face is quite sure to disintegrate or peel off in time. All laminated stones should always be laid on their natural bed. When freshly quarried, sandstones generally contain a considerable quantity of water, which makes them soft and easy to work, but at the same time very liable to injury by freezing if quarried in winter weather. Many Northern quarries cannot be worked in winter on this account. Almost all, if not all, sandstones harden as the quarry-water evaporates, so that many of them which are very soft when first quarried become hard and durable when placed in a building. Such stones, however, should not be subjected to much weight until they are dried out.

There is a great abundance of fine sandstone of all colors distributed throughout the United States, so that it is not difficult to get first-class stone for any building of importance. Most of the sandstones in the Eastern part of the country are either red or

brown in color, there being no merchantable light sandstones east of Ohio.

238. PRODUCTION OF SANDSTONE.—In 1906 Pennsylvania, New York, Ohio and California, with values of $1,346,140, $724,164, $659,611, $400,083 respectively, were the ranking States in the building-sandstone output.

239. DESCRIPTION OF SOME IMPORTANT SANDSTONES.—The following are some of the best-known sandstones in this country, any of which are good building stones:

Connecticut brownstone includes all the dark brown sandstones quarried in the neighborhood of Portland, Conn. It is a handsome dark brown stone, tinted slightly reddish, has a fine even rift, is easy to work, and gives a beautiful surface when rubbed. This stone is decidedly laminated, and the surface will soon peel if the stone is set on edge. When laid on its natural bed, however, it is very durable. This was the first sandstone quarried in the country, and great quantities of it have been used in New York City.

The following is a brief résumé of the properties of Connecticut brownstone and a list of some of the recent buildings in which it was used:

Color.—Brown, evenly laminated, uniform and permanent. No discoloration appears after many years' exposure to the weather.

Texture.—Sandstone, triassic, fine and even-grained. Easy to work. Free from clay, marl or gravel.

Uses.—Used for exterior and interior of churches, college buildings, public buildings, private houses, apartment-houses and all kinds of buildings; also for bridge masonry, retaining-walls, foundations, rubble masonry, pier, dyke and dock construction.

Strength.—Crushing strength from 13,330 to 15,020 pounds per square inch.

Chemical Properties.—Chemical analysis shows them to be as follows:

Silica	70.11
Alumina	13.49
Iron Oxide	4.85
Manganese	.35
Lime	2.39
Magnesia	1.44
Soda, Potash, etc	7.37
	100.00

The following is a short list of some recent buildings erected of this stone: Wesleyan University, Middletown, Conn., North College dormitory; Wesleyan University, Middletown, Conn., Fisk Hall; U. S. Government post-office, New Bedford, Mass.; U. S. Government post-office, Hoboken, N. J.; U. S. Government post-office, Bridgeport, Conn.; lining of chancel, St. Mark's Episcopal Church, Evanston, Ill.; Episcopal Church, Troy, N. Y.; Universalist Church, Meriden, Conn.; Caldwell H. Colt Memorial building, Hart-

ford, Conn.; High School building, Hartford, Conn.; John H. Hall Memorial building, Portland, Conn.; Packer Institute, Brooklyn, N. Y.; residence of Governor Murphy, Newark, N. J.; Canadian Bank of Commerce, Toronto, Canada.

Longmeadow Stone.—This is a reddish brown sandstone quarried principally at East Longmeadow, Mass. It is an excellent building stone, without any apparent bed, and may be cut in any way. It varies from quite soft to very hard and strong stone and should be selected for good work. It has been largely used throughout the New England States for the past twenty-five years.

The following are some of the specimen buildings in which the Longmeadow stone was used: Sever Hall, Harvard College, Cambridge, Mass.; Osborn Memorial Hall, Yale College, New Haven, Conn.; Marshall Field building, Chicago, Ill.; Trinity Church, Youth's Companion building, Mechanics' Arts high-school, Boston, Mass.; Waldorf-Astoria hotel, Teachers' College, New York; Commencement Hall and Library building, Princeton College, Princeton, N. J.; South Unitarian Church, Worcester, Mass.

Potsdam Red Sandstone, from Potsdam, N. Y., is a quartzite and one of the best building stones in the country, being extremely durable and equal to granite in strength. It was used in All Saints' Cathedral, Albany, N. Y., and in the Dominion Houses of Parliament, in Ottawa, Canada. There are three shades, chocolate, brick-red and reddish cream.

Hummelstown Brownstone, from Hummelstown, Pa., is a medium fine-grained stone, bluish brown or slightly purple in color, the upper layers being more of a reddish brown and much resembling the Connecticut stone. The stone compares very favorably with the other brownstones mentioned, and is in very general use in the principal Eastern cities.

The following is a short list of recent buildings constructed of this stone: North American building, Broad and Sansom streets, Philadelphia, Pa.; Emory M. E. Church, Pittsburg, Pa.; Corpus Christi R. C. Church, Buffalo, N. Y.; Market and Fulton National Bank, New York City; Wyatt building, 14th and F streets, Washington, D. C.; Arcade building, Cleveland, Ohio; court-house, Orlando, Fla.; First Universalist Church, Watertown, N. Y.; National Exchange Bank, Hopkins place, Baltimore, Md.; M. J. Heyer office-building, Wilmington, N. C.

North Carolina, West Virginia and *Indiana* contain quarries of brownstone which supply the local demand and the stones from which are worthy of a wider distribution, particularly those of North Carolina.

Fond du Lac, Minnesota, furnishes a reddish brown sandstone which closely resembles the Connecticut brownstone, but which is much harder and firmer. "The stone consists almost wholly of quartz cemented with silica and iron oxides."

Kettle River Sandstone.—At Banning, Minnesota, are quarries from which this stone is taken. It is a siliceous sandstone, and of a uniform light salmon color. It was used in the Main Library building, University of Illinois, Urbana, Ill.; in the interior of the United Presbyterian Church, at Worcester, Mass.; Spokane Club building, Spokane, Wash.; Public Library,

building, Des Moines, Iowa; court-houses at Elk Point, S. D.; Crookston, Grand Rapids and Benson, Minn.

Lake Superior Sandstones.—These are brown and red sandstones of the Potsdam formations. There are quarries at Portage Entry and Marquette, Mich., producing the red and brown shades, respectively, and at Port Wing, Wis., producing the brown shades. The Portage red sandstone was used in the Waldorf-Astoria hotel, Manhattan Savings Institution, Altman's new stores, New York; Board of Trade building, Toronto, Canada; Carnegie office-building, Pittsburg, Pa.; city-hall, Omaha, Neb. The Port Wing brown sandstone was used in the new armory building, St. Paul, Minn.; Carnegie Public Library building, Duluth, Minn.

Ohio Stone.—The finest quality of light sandstone in the United States is quarried in the towns of Amherst, Berea, East Cleveland, Elyria and Independence, Ohio, and is commonly known as "Ohio stone" or "Berea stone." It is a fine-grained, homogenous sandstone, of a very light buff, gray or blue-gray color, and is very evenly bedded. The stone is about 95 per cent silica, the balance being made up of small amounts of lime, magnesia, iron oxides, alumina and alkalies. There is but little cementing material, the various particles being held together mainly by cohesion induced by the pressure to which they were subjected at the time of their consolidation. They are very soft, work readily in every direction, and are especially fitted for carving.

"Unfortunately the Berea stone nearly always contains more or less iron pyrites and needs to be selected with care. Most of the quarries, however, have been traversed by atmospheric waters to such a degree that all processes of oxidation which are possible have been very nearly completed."*

The stone can be furnished in blocks of any desired size and uniform color. It is shipped to all parts of the country, and is in great demand for fine buildings. Mr. H. H. Richardson, the celebrated architect, often used it in contrast with the Longmeadow sandstone for trimmings and decorative effects. It contains from about 6 to 8 per cent of water when first taken from the quarry, and about 4 per cent when dry. It cannot be quarried in winter on account of the splitting of the stone caused by the freezing of the water contained in it. There are some fourteen or fifteen different companies that quarry this stone for the market.

The following are some representative buildings in which this Ohio sandstone has been used: Calvary M. E. Church, Allegheny, Pa., gray "Canyon" stone; Sixth United Presbyterian Church, Pittsburg, Pa., buff Amherst stone; Jewish Synagogue, Washington, D. C., Berea stone; Masonic Temple, Minneapolis, Minn., Berea stone; Planters' hotel, St. Louis, Mo., Berea stone; the Canadian Bank of Commerce, Winnipeg, Canada, gray "Canyon" stone; State Historical Library, Minneapolis, Minn., buff Amherst stone; O. N. G. armory, Cleveland, Ohio, Berea stone; city-hall, Milwaukee, Wis., Berea stone; city-hall, St. Louis, Mo., buff Amherst stone; city-hall, Davenport, Iowa, Berea stone; Taber opera-house, Denver, Col., buff.

"*The Waverly sandstone* comes from Southern Ohio. This is a fine-grained homogenous stone of a light drab or dove color, which works with

* "Stones for Building and Decoration." George P. Merrill.

facility, and is very handsome and durable. It forms the material of which many of the finest buildings in Cincinnati are constructed, and is, justly, highly esteemed there and elsewhere."*

Ohio is the largest producer of sandstone of any State in the Union.

At *Warrensburg, Mo.*, there is quarried a gray sandstone which has been used in many important buildings in Kansas City.

The Rocky Mountain region also furnishes great quantities of fine sandstones. In *Arizona* there is quarried a very fine-grained chocolate sandstone, which takes a fine edge and is excellently adapted for rubbed and moulded work. A considerable quantity of it is used in Denver, Col., on account of its pleasing color, and it is also shipped east of the Missouri River.

At *Manitou, Col.,* there are inexhaustible quarries of a fine red stone, much resembling the Longmeadow stone of Massachusetts, but of a lighter red color. It has no apparent bed and weathers well. It has sufficient strength for ordinary purposes. At *Fort Collins, Col.,* there is quarried a much harder and slightly darker stone, which is excellent for almost any purpose. It has sufficient strength for piers and columns, and is hard enough for steps and thresholds. It is much harder to cut than the Manitou stone, and hence is more expensive; but it is at the same time more durable. This stone has been shipped as far East as New York City. Colorado also contains an inexhaustible supply of sandstone flagging, admirably adapted for foundations and sidewalks; it is as strong as granite, and may be quarried in slabs of almost any size or thickness.

A red and buff sandstone is quarried at *Glenrock, Wyoming,* which has been used in Omaha, Nebraska.

The *Rawlins, Wyoming,* gray sandstone has been used in the following buildings: The Wyoming State Capitol and the United States post-office at Cheyenne, Wyo.; the State University at Laramie, Wyo.; court-house, school-house and State Penitentiary at Rawlins, Wyo.; residence of John F. Campion, Denver, Col.; court-house at Beatrice, Neb.; opera-house, Kearney, Neb.; public park building and several store buildings at San Francisco, Cal.

California has many quarries of sandstone, the larger number of which are in Santa Clara County. Stanford University is built of a light-colored sandstone quarried at San José, Cal.

Owing to the sparsely settled condition of the country and the lack of railroad facilities, the building stones of the Western portion of the United States have been but little developed, but with the building up of that part of the country the quarrying industry will undoubtedly become one of great importance.

6. SLATES.

240. GENERAL DESCRIPTION.—Although slate is not strictly a building stone, it is largely used for covering the roofs of buildings, for blackboards, sanitary purposes, etc., and the architect should be familiar with its qualities and characteristics.

* Ira O. Baker, "Masonry Construction."

The ordinary slate used for roofing and other purposes is a compact and more or less metamorphosed siliceous clay. Slate stones originated as deposits of fine silt on ancient sea bottoms, which in the course of time became covered with thousands of feet of other materials and finally turned into stone.

"The valuable constituents in slate are the silicates of iron and alumina, while the injurious constituents are sulphur and the carbonates of lime and magnesia."

One of the most valuable characteristics of slate is its decided tendency to split into thin sheets, whose surfaces are so smooth that they lie close together, thus forming a light and impervious roof covering. These plans of cleavage are caused by intense lateral pressure, and are generally at very considerable though varying angles with the ancient bedding.

The most valuable qualities of slate are its strength, its toughness and its non-absorptive character.

241. USES OF SLATE.—Slate is used principally for roofing purposes, but it is used also for billiard table tops, mantels, floor tiles, steps, flagging, fittings for toilet-rooms, school blackboards, school slates and pencils, electrical supplies and for numerous other purposes.

242. PHYSICAL PROPERTIES.—*Strength and Hardness.*—From various tests that have been made on the quality of slate, it appears that, in general, the strongest specimens are the heaviest and softest, as they are also the least porous and corrodible. "The tests for strength and corrodibility are probably those of greatest importance in forming an opinion regarding the value of the slate under actual conditions of service." *

Mr. Mansfield Merriman suggests that specifications should require roofing slates to have a modulus of rupture for transverse strength greater than 7,000 pounds per square inch.

If the slate is too soft the nail holes will become enlarged and the slate will get loose. If it is too brittle the slate will fly to pieces in the process of squaring and holing, and will be easily broken on the roof. "A good slate should give out a sharp metallic ring when struck with the knuckles; should not splinter under the slater's axe; should be easily 'holed' without danger of fracture, and should not be tender or friable at the edges."

* Mansfield Merriman in *Stone*, April, 1895.

The surface when freshly split should have a bright metallic luster and be free from all loose flakes or dull surfaces.

Color.—The color of slate varies from dark blue, bluish black and purple to gray and green. There are also a few quarries of red slates. The color of slate does not appear to indicate its quality. The red and dark colors are generally considered the most effective in appearance, while the greens are used principally on factories, storehouses and buildings where the appearance is not of so much importance.

Some slates are marked with bands or patches of a different color, and the dark purple slates often have large spots of light green upon them. These spots do not as a rule affect the durability of the slates, but detract greatly from their appearance.

As a rule the dark color of slates, particularly that of the slates of Maine and Pennsylvania, appears to be due to particles of carbonaceous matter contained in them.

"The red slates of New York are made up of a ground mass of impalpable red dust in which are imbedded innumerable quartz and feldspar particles."

Absorption.—A good slate should not absorb water to any perceptible extent, and if a slate is immersed in water half its height the water should not rise in the upper half; if it does, it shows that the slate is not of good quality.

"If, upon breathing upon a slate, a clayey odor be strongly emitted, it may be inferred that the slate will not weather."

Grain.—Good slates have a very fine grain. They should be cut lengthwise of the grain, so that if they break on the roof they will not become detached, but will divide each into two slates, each held by a nail.

Market Qualities.—The market qualities of slate are classed according to their straightness, smoothness of surface, fair, even thickness, and also according to the presence or absence of discoloration.

243. PRODUCTION OF SLATE.—There were 9 States reporting a commercial output of slate in the United States in 1906—Pennsylvania, Vermont, Maine, Virginia, Maryland, California, New York, Arkansas and Georgia, named in the order of value of output. Besides these States Arizona, New Jersey, Tennessee

and Utah have deposits more or less developed. The production for 1906 was reported as valued at $5,668,346.

There has been a gradual decrease in the number of squares of slate made in this country, due to a decrease of export trade, the English market, where American slates found considerable sale for several years, being now supplied either from the Welsh quarries, in consequence of the settlement of strikes in these quarries, or by small-sized, cheaper French roofing slates. The decrease is also due to labor troubles in the building trades for the last four or five years, to strikes in the slate quarries, and to the fact that the present building conditions in large cities do not call for slate roofs, the roofs being more nearly flat, and the large number of patent-roofing processes and tiles being cheaper and more convenient than the slate. This condition is, however, offset outside of cities, especially in the vicinity of quarries, by the high price of wooden shingles and the great durability of slate roofing. The scarcity and high price of labor has also been a factor in the decreased output. During the last five years smaller sizes of slate have been sold, making the average value lower. The roofing slate in 1906 was reported as 1,214,742 squares, valued at $4,448,786. Average value per square, $3.66 in 1906.

This table gives the number of "squares" of slate and the values of same, by States, for 1906:

	Squares.	Value.
California	10,000	$80,000
Georgia	1,000	5,000
Maine	18,498	100,916
Maryland	25,288	129,965
New York	10,788	60,000
Pennsylvania	755,966	2,710,249
Vermont	354,134	1,189,799
Virginia	39,068	172,857
Total	1,214,742	$4,448,786

A "square" of slate is the number of slates required to lay 100 square feet of roof, allowing a 3-inch lap. The estimated weight of roofing slate of ordinary thickness is 650 pounds to the square, and the slate is generally shipped in carload lots of from 50 to 90 squares per carload.

The following shows the average price of roofing slate per square

from 1901 to 1906 for the entire country: 1901, $3.15; 1902, $3.45; 1903, $3.88; 1904, $3.78; 1905, $3,69; 1906, $3.66.

There is practically no slate imported into the United States. In 1906 the importations were valued at $9,471, of which only $228 was for roofing slate.

The value of roofing slate exported from the United States in 1906 was $255,785, the chief slate export trade being to the United Kingdom, Canada and British Australasia.*

244. TRADE CLASSIFICATION OF SLATE.—Slates are classified in the trade by the name of the region in which they are quarried, some regions extending into two or more States. Several regions are contained in the State of Pennsylvania. The product from each region is more or less distinctive from that of other regions. The more important producing regions are:

Vermont and New York region; Bangor region, Pa.; Lehigh region, Pa.; Pen Argyl region, Pa.; Maine region; Northampton hard-vein region, Pa.; Peach Bottom region, Md. and Pa.; Virginia region.

The slates of the Bangor, Pen Argyl and Lehigh regions and the Northampton hard-veined slates are found in the extensive slate formation known as the Hudson River Division of the lower Silurian deposits; while the slate formations of Vermont, New York and Maine, and the Peach Bottom region, probably belong to the Cambrian Division, whose place in the geological series is lower and older than the Silurian rocks.

"The slates of the Cambrian formation are usually regarded as better in respect to strength and weathering qualities than those of the Silurian age, the market price of some varieties of the former being, indeed, more than double that of the common kinds of the latter."

245. DESCRIPTION AND LOCAL PRODUCTION OF SLATES FROM DIFFERENT STATES AND REGIONS.—

VERMONT AND NEW YORK REGION.—In the western portion of Vermont there are extensive quarries of slate, the product being used for all the different purposes for which the material is adapted.

Vermont ranks next to Pennsylvania in slate production, both in quantity and value of roofing slate, producing in 1906 29.15 per cent of the quantity of roofing slate. Almost the entire output is from Rutland County, in the vicinity of Castleton and West Castleton, Poultney, Fair Haven, North

* For further data regarding the production of slate in the United States see "Mineral Resources of the United States," calendar year 1906, from which much of this article is taken.

and South Poultney, Hydeville, Wells, Pawlet and West Pawlet, with a small output from Northfield, Washington County.

The stone is soft and uniform in texture, and can be readily planed or sawed like wood with a circular steel saw.

The slates from this region vary greatly in color, and are classified and sold under the following names:

"Sea-green," "unfading green," "uniform green," "bright green," "red," "bright red," "purple," "variegated" and "mottled."

The true "sea-green" slate is found in this State, but it fades and changes color badly.

Red Slate.—Nearly all the red slate used in the United States is quarried in the neighborhood of Granville and Middle Granville, Washington County, near the Vermont line, in New York State. "The slates of this formation are of a brick-red and green color, both varieties often occurring in the same quarry." The slate is of good quality and is used almost entirely for roofing purposes, its color making it especially desirable for fine residences and public buildings. Owing to the limited quantity, this slate brings about three times the price of the dark slates.

MAINE REGION.—The quarries in this region are located at Monson, Blanchard and Brownville, Piscataquis County. The stone is of a blue-black color, of excellent quality, being hard, yet splitting readily into thin sheets with a fine surface. The slates are not subject to discoloration, and give forth a clear ringing sound when struck. The Brownville slate is said to be the toughest in the world. Slate from this quarry, after fifty years' exposure, looks as bright and clean as when new.

The Maine quarries furnish nearly all the black slates used in New England. The product is also extensively used for school slates, blackboards and sanitary purposes.

PENNSYLVANIA SLATES.—Pennsylvania, from the three producing counties, Northampton, Lehigh and York, produced in 1906 62.13 per cent of the slate output of the United States. Of the roofing slate the number of squares produced in Pennsylvania represented 62.34 per cent of the quantity of roofing slate produced in the United States. Northampton County produced 71.16 per cent of the Pennsylvania output and 44.28 per cent of the total for the United States; Lehigh County 27.32 per cent of the Pennsylvania output and 17 per cent of the total, and York County 1.52 per cent of the Pennsylvania output and 0.94 per cent of the total.

The number of squares and values of same for 1906 by counties are as follows:

	Squares.	Value.
York County	11,468	$59,833
Lehigh County	206,505	741 933
Northampton County	537,993	1,908,483
Totals	755,966	$2,710,249

Bangor Region.—This region is entirely within Northampton County, and is the most important, in point of production, in the country. The principal

quarries are at Bangor, East Bangor and Slatington. The color is a uniform dark blue or blue-black. This slate is used very extensively for blackboards and school slates, as well as for roofing purposes. The average modulus of rupture is 9,810 pounds per square inch.

The *Lehigh region* includes all of Lehigh County, a few quarries in Berks and Carbon Counties and regions opposite Slatington in Northampton County. The product is similar to that of the Bangor region.

The *Pen Argyl region* embraces quarries at Pen Argyl and Wind Gap in Northampton County.

The *Northampton hard-vein region* includes the Chapman, Belfast and other quarries, all in Northampton County. This region is distinguished on account of the extreme hardness of the slate as compared with that produced in other regions of the State. The product is considered the best of the Silurian slate, its extreme hardness being generally considered an advantage, rendering it durable and non-absorbent. It is especially suitable for flagging. The average modulus of rupture is about 8,480 pounds per square inch.

PEACH BOTTOM REGION.—The celebrated "Peach Bottom Slate" is taken from a narrow belt scarcely 6 miles long and a mile wide, extending across the southeastern portion of York County and into Harford County, Maryland. The Maryland slate is produced at Cardiff, Harford County, a continuation of the "Peach Bottom" region at Delta, York County, Pa. The stone is tough, fine and moderately smooth in texture, blue-black in color, and does not fade on exposure, as has been proven by seventy-five years' wear on the roofs of buildings. It also ranks very high for strength and durability, and is generally considered equal, if not superior, to any slate in the country. The average modulus of rupture of twelve specimens was 11,260 pounds, the lowest value being 8,320 pounds per square inch.

THE NORTHERN PENINSULA OF MICHIGAN contains an inexhaustible supply of good roofing slate, and quarries were at one time worked about 15 miles from L'Anse and about 3 miles from Huron Bay. No slate has been produced from there, however, since 1889. "The stone here is susceptible of being split into large, even slabs of any desired thickness, with a fine, silky, homogenous grain, and combines durability and toughness with smoothness. Its color is an agreeable black and very uniform." *

VIRGINIA.—A good blue-black roofing slate is quarried commercially at Arvonia, Ore Bank and Penlan, Buckingham County.

GEORGIA.—Quarries in Polk County, Georgia, furnish most of the roofing slates for Atlanta and neighboring towns.

OTHER STATES.—Good roofing slate is found also in other States, but the quarries have not been recently worked, or not opened at all, or not worked commercially to any great extent.

7. MISCELLANEOUS BUILDING STONES.

264. LAVA STONE, TUFFS OR TUFA.—Near Castle Rock, in Colorado, is quarried a soft, very light gray and pink stone

* "Stones for Building and Decoration." George P. Merrill.

of volcanic origin, which is commonly called "lava stone." It is extremely light, weighing only from 75 to 110 pounds per cubic foot, and it can be cut with a knife. It weathers better than the soft sandstones, and its color makes it very suitable for rock-faced ashlar. It is difficult to obtain in large blocks, and is full of clay or air holes and often of invisible cracks, which render it dangerous for use in heavy buildings; but for dwellings it makes a very cheap, durable and pleasing stone. Owing to the small air holes which it contains it does not receive a finished surface, and is most effective when used in rock-faced work. There are a great many houses and several public buildings in Denver built of this stone. A similar stone occurs in the vicinity of the Las Vegas Hot Springs and Albuquerque, New Mexico.

247. BLUE SHALE.—This is a variety of sandstone that is dark blue in color, quite dense and hard, and makes a fair material for foundations. As a rule it does not work readily and often contains iron pyrites, which render it unsuitable for ashlar or trimmings.

248. TRAP.—The only stone in many localities is a hard, igneous rock, called *trap,* which is suitable for foundations, but cannot be cut easily. Such stones are used for local purposes only, and when none other can be obtained except at great expense.

249. SOAPSTONE.—Although not properly a building stone, soapstone is used more or less in the fittings of buildings, especially for sinks and wash-trays.

It is a dark bluish gray rock, composed essentially of the mineral talc.

It is soft enough to be cut readily with a knife, or even with the thumb nail, and has a decided soapy feeling, which gives it its name. Although so soft, it ranks among the most indestructible and lasting of rocks. At present its chief use is in the form of slabs about 1¼ inches thick, for stationary wash-tubs and sinks, for which it is one of the best materials. Soapstone also offers great resistance to heat, and is often used for lining fireplaces.

At one time it was extensively used in New England in the manufacture of heating- or warming-stones. Considerable quantities of powdered soapstone are used for making slate-pencils and crayons, as a lubricant for certain kinds of machinery, and in the finishing coat on plastered walls.

The principal quarries producing block stone are situated in the States of New Hampshire, Vermont and Pennsylvania.

The State of North Carolina produces most of the powdered soapstone, which is quarried in small pieces and ground in a mill.

8. SELECTION OF BUILDING STONES.

250. GENERAL CONSIDERATIONS.—The selection of stones for structural purposes is a matter of the greatest importance, especially when they are to be used in the construction of large and expensive buildings. The cities of Northern Europe are full of failures in the stones of important structures, and even in the cities of the northern portion of the United States the examples of stone buildings which are falling into decay are only too numerous.

"The most costly building erected in modern times, the Parliament House in London, was built of a stone taken on the recommendation of a committee representing the best scientific and technical skill of Great Britain. The stone selected was submitted to various tests, but the corroding influences of a London atmosphere were overlooked. The great structure was built of magnesian limestone, and now it seems questionable whether it can be made to endure as long as a timber building would stand, so great is the effect of the gases of the atmosphere upon the stone." *

Stone should be studied with reference to its hardness, durability, beauty, chemical composition, structure and resistance to crushing.

251. NEW STONES.—If, in selecting a building stone, it is deemed advisable to use one from a new quarry, and if its weathering qualities have not been tested by actual use in buildings, the architect should insist upon a chemical and microscopic test by an expert to see if there is anything in its composition or structure which would render it unsuitable for building purposes. If the report is favorable, and if the stone meets the tests described in the following sections, he may then use it with a free conscience.

An architect cannot be too careful about using a new stone, or one that has not been used under circumstances similar to the new ones; and whenever he is obliged to use such stone he should take pains to obtain as much information in regard to it as possible from all practical sources.

The writer has known of a case in which a certain kind of stone,

* Ira O. Baker in "Masonry Construction."

which had for a long time been used for making ashlar, was used in the piers under a seven-story building. The piers commenced to crack under only about one-one-hundredth part of the breaking strength as given in a published report of strength tests, and it cost nearly $200,000 to repair the damage and to substitute other stone. It was a lava stone, and its failure was supposed to be due to fine cracks produced in blasting out the stone from the quarry.

It will not always do, either, to rely upon the past reputation of a stone for durability, as the quality of one building stone may differ from that of another from the same quarry.

252. CLIMATE AND LOCATION.—In selecting a building stone the climate, together with the location, with especial reference to the proximity to large cities and manufacturing establishments, should be first considered. There are many porous sandstones or limestones which could endure an exposure of hundreds of years in a climate like that of Florida, New Mexico, Colorado or Arizona, but which would be sadly disintegrated at the end of a single season in one of the Northern States. The climate of our Northern and Eastern States, with an average annual precipitation of from 30 or 40 inches and with a variation in temperature sometimes reaching 120 degrees Fahr., is very trying to stonework; and unless the stones used are suited to the conditions in which they are placed, they are liable to decay and utter failure.

253. EFFECTS OF CHANGES IN TEMPERATURE.—The most trying conditions to which building stones are subject are the ordinary changes of temperature which prevail in the Northern and Eastern States. "Stones, as a rule, possess but a low conducting power and slight elasticity. They are aggregates of minerals, more or less closely cohering, each of which possesses degrees of expansion and contraction of its own. As temperatures rise each and every constituent expands more or less, crowding with resistless force against its neighbor; as the temperatures decrease a corresponding contraction takes place. Since the temperatures are ever changing, often to a considerable degree, so, within the mass of the stone, there is continual movement among its particles. Slight as these movements may be they can but be conducive of one result, a slow and gradual weakening and disintegration." * This is supposed to be the chief cause of the disintegration of granites.

There are several examples of old stonework in New York City

* "Stones for Building and Decoration." George P. Merrill.

in which the stone has begun to decay on the south and west sides, where the sun shines the longest, but in which it has not begun to decay on the north and east sides. The efforts of moderate temperatures upon stones of ordinary dryness are, however, slight compared with the effects of freezing upon stones saturated with moisture. The pressure exerted by water in passing from a liquid to a solid state amounts to not less than 138 tons to the square foot; and it is, therefore, evident that any porous stone exposed to heavy rains and to a temperature several degrees below the freezing point must be seriously damaged by a single season's exposure. It is also evident that the more *porous* a stone is the greater will be the deterioration; and as sandstones are the most porous of all building stones, they suffer the most from this cause and granites suffer the least. Granite is, accordingly, the best stone for a base-course or for underpinning.

For the effect of absorption on the durability of stones see Article 263.

254. DURABILITY OF DIFFERENT STONES.—The durability of a stone is naturally of the first importance; for unless it lasts a reasonable length of time, the money spent on a structure will be largely wasted. All public buildings should be built of materials practically imperishable.

Table XXIII, taken from the Report of the Tenth Census, 1880, Vol. X, p 391, gives the number of years that different stones have been found to last in New York City, without discoloration or disintegration to the extent of necessitating repairs:

TABLE XXIII.

Durability of Different Stones.

Coarse brownstone	5 to 15
Fine laminated brownstone	20 to 50
Compact brownstone	100 to 200
Bluestone (sandstone), untried	Probably centuries
Nova Scotia sandstone, untried	Perhaps 50 to 200
Ohio sandstone (best siliceous variety),	Perhaps from one to many centuries
Coarse fossiliferous limestone	20 to 40
Fine oolitic (French) limestone	30 to 40
Marble, coarse dolomite	40
Marble, fine dolomite	60 to 80
Marble, fine	50 to 100
Granite	75 to 200
Gneiss	50 years to many centuries

There are many circumstances and conditions, aside from the quality of the stone, that affect the durability of exposed stonework, the more important of which are heat and cold, composition of the atmosphere, position of the stone in the building, and manner of dressing the stone.

255. EFFECT OF ATMOSPHERIC ACTION ON BUILDING STONES.—The chemical action of the gases of the atmosphere, when brought by rain in contact with the surfaces of certain stones, seriously affects their durability. The most important changes produced by these agencies are (1) oxidation and (2) solution.

(1) *Oxidation.*—The process of oxidation is, as a rule, confined to those stones which contain some compound of iron, and particularly that known as pyrite or iron disulphide. If the iron exists in the latter form it generally combines with the oxygen of the air, forming the various oxides and carbonates of iron, such as are popularly known as "rust."

"If the sulphide occurs scattered in small particles throughout a sandstone the oxide is disseminated more evenly through the mass of the rock, and aside from a slight yellowing or mellowing of the color, as in certain Ohio sandstones, it does no harm. Indeed, it may result in positive good, by supplying a cement to the individual grains and thus increasing the tenacity of the stone."*

If the pyrite exists in pieces of any size, however, it is almost sure to oxidize and stain the stone so as to ruin its appearance, especially if it is of a light color.

In all stones other than sandstones the presence of any pyrite is a very serious defect, as it is almost sure to rust them and may also render them porous and more liable to the destructive effects of frost.

(2) *Solution.*—The worst effect of the action of the gases of the atmosphere in connection with rain is the dissolving of certain constituents of stones, thereby causing their decomposition. Pure water alone is practically without effect on all stones used for building, but in large cities, and particularly in those in which a great deal of coal is consumed, the rain absorbs appreciable quantities of sulphuric, carbonic and other acids from the air, conveys them into

* "Stones for Building and Decoration." George P. Merrill.

the pores of the stones and very soon destroys those whose constituents are liable to be decomposed by such acids.

Carbonate of lime and carbonate of magnesia, the principal constituents of ordinary marbles, limestones and dolomites, are particularly affected by the solvent action of these acids, even when they are present only in very minute quantities; and on this account these stones are extremely perishable in large cities and manufacturing towns. Of course in dry climates the acids are not conveyed into the stone to any great extent, and the stones last much longer than they do in a damp climate. The less absorbent a stone is the less will be the solvent action of the acids, and the longer it will last. Dolomites are in this respect more durable than limestones.

Sandstones, whose cementing material is composed largely of iron or lime, are also subject to rapid decay through the solvent action of the acidulated rains. The feldspars of granites and other rocks are also responsive to the same influence, though in a less degree.

256. METHOD OF FINISHING BUILDING STONES.—This also has a great deal to do with the durability of a stone. As a rule, the less jar from heavy pounding that the surface is subjected to the more durable will be the surface, for the reason that the constant impact of the blows tends to destroy the adhesive or cohesive power of the grains, and thus renders the stone more susceptible to atmospheric influences. This applies particularly to granites and limestones. Only granites and the hardest sandstones should be pene- or bush-hammered; all others, if dressed, should be cut with a chisel. Sandstones may afterward be finished with a crandall, if desired. For granites a rock-face surface is probably the most durable, since the crystalline facets thus exposed are best fitted to shed moisture and the natural adhesion of the grains is not disturbed. For all other stones, however, a smoothly sawn, rubbed or polished surface seems best adapted to a variable climate.

257. MANNER OF SETTING STONES.—When a stone is built into the wall of a building in such a way that the natural layers of the stone are vertical, or on edge, the water penetrating the stone and freezing there causes its surface to exfoliate or peel off much more quickly and to a much greater extent than is the case when it is laid with its natural bed horizontal.

Stones also so placed in a building that rain strikes them and washes over them, such as sills, belt-courses, etc., decay sooner than

the ashlar forming the face of the wall, and should be of the most durable material.

258. THE COLOR OF STONES.—The great governing point with an architect in selecting a building stone is generally its color. In this again he is limited to a choice between those stones which come within the limit of cost. But the question of durability should always be borne in mind. Architects, owners and contractors should always keep in mind not only how a building will look when just completed, but how it will appear at the end of a few years, and, again, at the end of half a century. And probably it is better to accept shades of color which may be a little harsh and inharmonious at first, if durability is gained thereby, than to use the most pleasing color only to see it entirely changed at the end of a year, and crumbled to pieces at the end of a decade.

A durable stone of any color generally tones down and becomes more pleasing at the end of a few years, while one that is not durable and permanent in color very soon becomes an eyesore.

In the country and in small towns where there is no manufacturing, and where little bituminous coal is used, light-colored stones may be used with the prospect of having their color remain unchanged; but in large cities and manufacturing towns, and particularly in those in which bituminous coal is the principal fuel, light stones should be avoided. For the last-mentioned localities red or brown siliceous sandstones are the most enduring and permanent, and next to these come the granites.

In cities like Chicago, St. Louis, Pittsburg, Cincinnati, etc., the darker the stone used the more permanent will be its color, that is, in the central portions of the cities, as both brick and stone assume a dirty, dark bronze color in a few years, and in such localities delicate colors and fine carving are out of place.

In climates like that of Colorado, Arizona and New Mexico, where there is a very bright sun and almost no rain, the light stones, and particularly the marbles, are most effective, as the shadows on such stones are very marked, and all kinds of ornament are made much more prominent than on red or dark stones. Any compact stone will last for centuries above the ground.

As a rule, other things being equal, those stones which hold their native color the best will be the most beautiful in a building; and

of the stones which do change color, those will be the most desirable which change the least and the most evenly.

259. THE COST OF BUILDING STONES.—This has often more to do with the choice of a building stone by the owner than the architect wishes. The cost of a stone when cut depends not only upon the cost of the rough stone delivered at the site, but also upon the ease with which it may be worked; upon whether it is to be smooth or rock-face; plain or moulded; and also, to some extent, upon its weight. One stone may be cheaper than another in the rough, but the extra labor of cutting may make it the more expensive when built into the wall. The heavier a stone is the greater will be the cost of setting and of transportation.

260. THE HARDNESS OF BUILDING STONES.—For many purposes the hardness of a stone must be considered, as, for example, when it is to be used for steps, door sills, paving, etc. Granites, quartzites, or siliceous sandstones, and bluestones are the best for this purpose.

261. THE STRENGTH OF BUILDING STONES.—Whenever any kind of stone is to be used for foundations, piers, lintels, or bearing-stones, etc., its strength should be considered, and if this has not been demonstrated to be sufficient by practical use under similar circumstances, cubes of the stone measuring about 6 inches on a side should be carefully tested for the crushing strength. If it has every appearance of being a first-class stone of its kind, its strength may be assumed to be equal to the average strength of stones of that kind. The safe working strength for piers, etc., should not exceed one-tenth of the crushing strength. Tables giving the crushing strength of many well-known stones and the safe working strength for stone masonry are given in the Appendix.

The method according to which a stone is quarried sometimes has much to do with its strength. If it is quarried by means of explosives it may contain minute cracks, which cannot be discovered until it receives its load, when their presence is unpleasantly manifested. Such an occurrence could take place only in some stone like a lava or a conglomerate. The cracking and splitting of stones in buildings are due more often to *imperfect setting* than to lack of strength in the stones themselves. All stones that will meet the requirements for durability will have sufficient strength for all purposes, except when they are in the positions mentioned above.

262. FIRE RESISTANCE OF BUILDING STONES.*—The property in a stone of resisting the action of fire is often of much consequence, especially when there is exposure to fire risks on all sides, as is the case with most business blocks. Of the different kinds of stone used for building, the compact, fine-grained sandstones withstand the action of fire the best; limestones and marbles suffer the most, being calcined by an intense heat; and granites are intermediate in regard to injurious effects. The best sandstones generally come out uninjured, with the exception of the discoloration caused by smoke. Granites do not always collapse, but the face of the stone generally splits off and flies to pieces, often with explosive violence.

9. TESTING OF BUILDING STONES.

263. GENERAL CONSIDERATIONS.—Every stone intended for building purposes that does not come from some well-known quarry should be tested by chemical analysis and the results compared with the analysis of well-known stones of the same kind; and if found to differ materially in those constituents which are soluble in water or attacked by sulphuric or carbonic acids it should be rejected. The presence also of iron pyrites should lead to the rejection of the stone if it is intended for exterior use. If the building is one of importance the architect should insist on the owners getting the opinion of some expert chemist or mineralogist on the durability and weathering qualities of the stone in question.

As a rule, however, most buildings are now built with stone which is taken from well-known quarries, and whose weathering qualities have been tested; so that if the quality is equal to the best that the quarry will supply, the stone will prove all that was expected of it. The fact, however, that certain quarries have furnished good material in the past is no guarantee of the future output of the

* For recent and valuable data on the fire resistance of building stones the reader is referred to the very interesting paper by W. E. McCourt, on "The Fire-Resisting Qualities of Some New Jersey Building Stones, Part I," in "The Annual Report of the State Geologist for 1906."

Mr. McCourt collected a number of samples of New Jersey stones during the summers of 1904 and 1905, under the direction of the State Geologist, and these were tested in the Geological Laboratory of Cornell University, in connection with work for advanced degrees. The object of the investigation was to ascertain the relative tendency of various stones to withstand extreme heat, and to determine, as far as possible, the criteria which control the refractory properties.

The report includes an outline of earlier investigations, observations on burned buildings, methods of making the fire tests, samples tested, general summary of results with granites and gneisses, diabases, sandstones, limestones and argillite, and a detailed statement of experiments, with numerous illustrations.

The reader is referred also to the Appendix.

entire quarry. This is especially true regarding rocks of sedimentary origin, like the sandstones and limestones, different beds of which will often vary widely in color, texture, composition and durability, although lying closely adjacent. In many quarries of calcareous rocks in Ohio, Iowa and neighboring States the product is found to vary at different depths, all the way from pure limestone to magnesian limestone and dolomite, and in many cases an equal variation exists in point of durability.*

The architect should, therefore, make a careful examination of the stone as it is delivered on the ground, or in the yard and before it is cut, to see that the quality of the stone is up to the standard required; and in large buildings in which a great quantity is required it is advisable to visit the quarry and to determine from what part of it the stone shall be taken.

The following rules and tests will enable one to judge if a stone is of good quality and likely to prove durable:

Compactness.—As a general rule, in comparing stones of the same class, the least porous, most dense and strongest will be the most durable in atmospheres which have no special tendency to attack their constituent parts. Good building stones should also give out a clear, ringing sound when struck with a hammer.

Fracture.—A fresh fracture, when examined through a powerful magnifying glass, should be bright, clean and sharp, with the grains well cemented together. A dull, earthy appearance indicates stone likely to decay.

Absorption.—One of the most important tests for the durability of stone is that of the porosity or degree to which it absorbs moisture; since, other things being equal, the less moisture it absorbs the more durable it will be.

To determine the absorbent power the specimen is thoroughly dried in a temperature of about 100 degrees Fahr., and carefully weighed; then soaked for at least twenty-four hours in pure water; then removed from the water, and the surface allowed to dry in the air; and then weighed. The increase in weight is the amount of water absorbed, and stands, although not absolutely correct, as an expression of the stone's absorbent power. This test is extremely simple, and when done with care gives very practical results.

Any stone which absorbs 10 per cent of its weight of water dur-

* "Stones for Building and Decoration." George P. Merrill.

ing twenty-four hours should be looked upon with suspicion until, by actual experiment, it shows itself capable of withstanding, without harm, the different effects of the weather for several years. Half of this amount may be considered too large when the stone contains any appreciable amount of lime or clayey matter.*

The porosity of a stone also has an effect upon its appearance when in a building.

A non-absorbent stone is washed clean by each heavy rain, and its original beauty is retained; while a porous stone soon fills with dirt and smoke and looks little better than a stone plastered with cements. Even in stones for interior decoration absorption should not be overlooked, as ink, oils or drugs may ruin expensive furnishings if the stones used are porous.

Acid Test.†—Simply soaking a stone for some days in dilute solutions containing 1 per cent of sulphuric acid and hydrochloric acid will afford a rough idea as to whether or not it will stand a city atmosphere. A drop or two of acid on the surface of the stone will create an intense effervescence if there is a large proportion present of carbonate of lime or carbonate of magnesia.

Test for Solution.—The following simple test is useful for determining whether a stone contains much easily dissolved earthy or mineral matter:

Pulverize a small piece of the stone with a hammer, and put the pulverized portion into a glass filled about one-third with clear water, and let it remain undisturbed for at least half an hour. Then agitate the water and broken stone by giving the glass a circular motion with the hand. If the stone is highly crystalline, and the particles well cemented together, the water will remain clear and transparent; but if the specimen contains uncrystallized earthy powder the water will present an appearance more or less turbid or milky, depending upon the quantity of loose matter contained in the stone.

10. SEASONING OF STONE.

264. GENERAL CONSIDERATIONS.—All stone is better for being exposed to the air before it is set until it becomes dry. This gives a chance for the quarry water to evaporate, and in nearly all

* "Stones for Building and Decoration." George P. Merrill.
† "Notes on Building Construction," Part III, p. 11.

cases renders the stone harder, and prevents it from splitting from the action of the frost.

Many stones, particularly certain varieties of sandstones and limestones which are quite soft and weak when first quarried, acquire considerable hardness and strength after they have been exposed to the air for several months. The following is supposed to be the cause of this hardness. The quarry-water contained in the stone holds in solution a certain amount of cementing material, which, as the water evaporates, is deposited between the particles of sand, binding them more firmly together and forming a hard outer crust to the stone, while the inside remains soft, as at first. On this account the stone should be cut soon after it is taken from the quarry, and if any carving is to be done it should be done before the stone becomes dry, otherwise the hard crust will be broken off and the carving will be on the soft interior, and consequently have its durability much impaired.

II. PROTECTION AND PRESERVATION OF STONEWORK.

265. GENERAL CONSIDERATIONS.—There are a great many preparations that have been used for preventing the decay of building stones, but all are expensive, and none have proved entirely satisfactory.

Paint.—One material very generally used for preserving stonework is lead and oil paint. This is effectual for a time, but the paint is destroyed by the atmospheric influences, and must be renewed every three or four years. It also spoils the beauty of the stone.

The White House at Washington is built of a porous red sandstone, which has been painted white for many years.

Oil.—Boiled linseed oil is sometimes used on stonework, but it always discolors a light-colored stone, and renders a dark-colored one still darker. "The oil is applied as follows: The surface of the stone is washed clean, and, after drying, is painted with one or more coats of boiled linseed oil, and finally with a weak solution of ammonia in warm water. This renders the tint more uniform. This method has been tried on several houses in New York City, and the waterproof coating thus produced found to last about four or five years, when it must be renewed. The preparation used in coating the Egyptian obelisk in Central Park is said to have consisted of paraffine containing creosote dissolved in turpentine, the creosote

being considered efficacious in preventing organic growth upon the stone. The melting point of the compound is about 140 degrees Fahr. In applying the preparation the surface to be coated is first heated by means of specially designed lamps and charcoal stoves, and the melted compound applied with a brush. On cooling it is absorbed to a depth dependent upon the degree of penetration of the heat. In the case of the obelisk the depth was about ½ of an inch."*

A soap and alum solution also has been used with moderate success for rendering stone waterproof.

Ransome's Process.—This consists in applying a solution of silicate of soda or potash, water-glass, to the surface of the stone, after it has been cleaned, with a whitewash brush until its surface has become saturated. After it has become dry a solution of chloride of calcium is freely applied so as to be absorbed with the silicate into the structure of the stone. The two solutions produce by double decomposition an insoluble silicate of lime, which fills the pores of the stone and binds its particles together, thus increasing both its strength and weathering qualities. This process has been used to a considerable extent in England, and is perhaps the most successful of all applications. The process of applying the solutions is more fully described in "Notes on Building Construction," Part III, p. 78.

12. ARTIFICIAL AND MANUFACTURED STONES.

266. GENERAL DESCRIPTION.—A brief mention is made here of the so-called "artificial stones" and "manufactured stones," although it may be claimed that they belong more properly, in any strict classification, to such products as hydraulic cement products, sand-lime products, etc.

Artificial cement stones are usually carefully made blocks of cement mortar rendered compact by ramming or compressing such mortar in the moulds, and given any desired shape by using suitable moulds. To this class belongs the "Beton Coignet," used in France.

An artificial stone, made by a different process, is called "Ransome Stone." The mortar is made of sand, silicate of soda and water, and is compressed into moulds in the usual way. A hot solution of calcium chloride is then provided, into which the stone is

* "Stones for Building and Decoration." George P. Merrill.

immersed under pressure, causing a calcium silicate to form, and resulting in an insoluble cement, and also in a sodium chloride, which latter is removed by washings.

Several kinds of artificial stone are manufactured under patented processes, and many are combinations of hydraulic cement, sand, pebbles, stone-dust, etc., with or without the addition of some indurating material, as baryte, letharge, etc. They are manufactured either in place or in the form of blocks at the factories.

To several of the sand-lime products the name "manufactured stone" has been given by the manufacturers. A product, consisting essentially of silica and lime, is in England called "silicate stone." The proportion of lime used is from 5 to 10 per cent, the purity of the silica regulating the quantity.

A sand-lime product is manufactured at Wilmington, Delaware, by the Diamond Stone-Brick Company, and called "Wawaset Limestone." The manufacturers claim that the principle underlying its production has been successful for about twenty years, but that its application has not been made commercial until recently. The process is a secret, but it is admitted that it contains no cement whatever, and that it is along the lines of those employed in the manufacture of sand-lime bricks. If the sand-lime brick theory is a correct one, and there seems to be strong evidence that it is, then this material, supplied on a large scale, should be good, providing the process can be so well carried out that large stones are thoroughly permeated the same as are small bricks.

Quite elaborate tests have been made on these products, and very satisfactory results shown, not only when considered in relation to the manufactured stones themselves, but also when compared with the results of comparative tests made with natural limestones, sandstones, etc.

The Wawaset manufactured limestone has been used in several buildings for both exterior and interior purposes and lends itself well to carved, moulded and decorative work of all kinds. It was used in the Spring Garden Street Branch Library building in Philadelphia, and in other buildings in the same city and in Wilmington, Delaware.

In regard to the products including hydraulic cement mortar and concrete constructive and decorative stones there are a number of companies making them in different parts of the United States. At New Haven, Conn., the Economy Manufacturing Company makes

a concrete building stone, the process involved in which is without secrets or patents, and consists in the pouring of crushed trap rock and cement into a form, letting it stay there about two days, and then rubbing it down in various ways. It is entirely similar to the concrete used in footings and foundations, except that it has about three times the amount of cement usually put into the latter constructions, and is mixed with much greater care.

The artificial concrete stone products of this company have been used in several important buildings, such as the new Cadet Barracks at West Point, N. Y.; Christ Church, West Haven, Conn.; Trinity Church, New Haven, Conn.; St. Philip's Church, Durham, N. C.; St. James' Church, Woodstock, Vt., etc.

CHAPTER VI.

Cut-stonework.

267. INTRODUCTORY.—In order to properly lay out, detail and specify the stonework of a building, it is necessary to have a thorough knowledge of the different tools and processes employed in cutting and dressing the stone and of the different ways in which stone is used for walls, ashlar and trimmings.

The description in this chapter of different classes of work, supplemented by critical observation in the stone-yard and at the building, should give one a good idea of the ordinary methods and practices employed in this country.

The subject of cut-stonework may be conveniently discussed under seven subdivisions, as follows:

1. Classes of Cut-stonework.
2. Stone-cutting and Finishing.
3. Miscellaneous Trimmings.
4. Treatment of Cut-stonework in the Wall.
5. Strength of Cut-stonework.
6. Measurements and Cost of Cut-stonework.
7. Superintendence of Cut-stonework.

1. CLASSES OF CUT-STONEWORK.

Stonework, such as is used in the superstructure of buildings, may be divided into three classes: Rubble-work, Ashlar and Trimmings.

268. RUBBLE-WORK.—This is used only for exterior walls in places where suitable stone for cutting cannot be obtained at a relatively low price. There are localities which furnish cheap, durable stone which cannot be easily cut, such as the conglomerates and slate stones. They generally split so as to give one good face, and may be used with good effect for walls, with cut-stone or brick trimmings.

Fig. 93 shows the usual method of building a rubble wall above ground. After the wall is up the joints are generally filled flush with mortar of the same color as the stone, and a raised false joint

of red or white mortar stuck on, to imitate ashlar. Such work should be specified to be laid with beds and joints undressed, projections knocked off and laid at random and interstices filled with spalls and mortar. If a better class of work is desired, the joints and beds should be hammer-dressed.

Fig. 94 shows a kind of rubble-work sometimes used for buildings, which is quite effective for suburban architecture. It should be specified to have hammer-dressed joints, not exceeding ½ or ¾ of an inch, with no spalls on the face. This is generally expensive work.

Fig. 95 shows a rubble wall with brick quoins and jambs.

Occasionally small boulders or field-stone are used for the walls of rustic buildings. In such cases the walls should be quite thick,

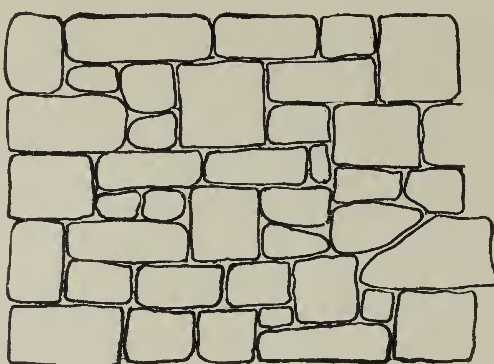


Fig. 93.—Rubble Stonework, Undressed, Laid at Random.

with backings of split stone, to hold the boulders; and the exact manner in which the walls are to be built should be specified. There are several kinds of rubble used in engineering work, but the above are about the only styles used in buildings.

269. ASHLAR.—The outside facing of a wall, when of cut-stone, is called *ashlar,* without regard to the way in which the stone is finished. Ashlar is generally laid either in continuous courses, as in Figs. 96 and 97, or in broken courses, as in Fig. 101; or without any continuous horizontal joints, as in Figs. 98 and 99, which represent *broken-ashlar.*

270. COURSED-WORK.—Coursed-work is always the cheapest when stones of a given size can be readily quarried, as is usually the case with sandstones and limestones. The cheapest ashlar for

most stones is that which is cut into 12-inch courses, with the length of the stones varying from 18 to 24 inches. When they are cut from 30 inches to 3 feet in length, and with the end joints plumb over each other, as in Fig. 96, the cost is considerably increased, and if this kind of work is desired it should be particularly specified.

Fig. 96 is regular-coursed-ashlar, each course being the same height with plumb bond. When the courses of stone are of different heights it is called irregular-coursed-ashlar.

A form of ashlar now much used is that shown in Fig. 97, in which wide and narrow courses alternate with each other. Six inches and 14 inches make good heights for the courses.

Fig. 102 shows regular-coursed-ashlar, with rustic quoins and plinth, which is much used in Europe.

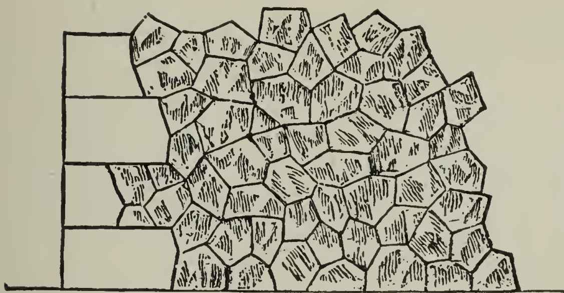


Fig. 94.—Random-Rubble Stonework with Hammer-dressed Joints and No Spalls on Face, and with Quoins.

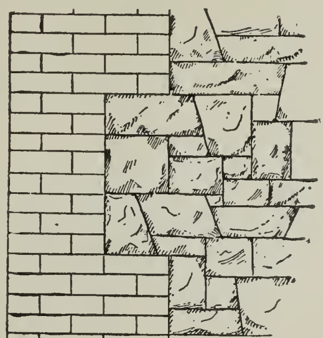


Fig. 95.—Dressed Rubble Stonework with Brick Quoins and Brick Jambs.

271. BROKEN-ASHLAR.—When stones of uniform size cannot be cheaply quarried the stone may be used to better advantage in broken-ashlar, but it takes longer to lay it, and, as a rule, broken-ashlar costs considerably more than coursed-ashlar. This style of work is generally considered the most pleasing, and, when done with care, makes a very handsome wall, as shown by the half-tone illustration, Fig. 100. It is generally used for rock-face work only. To present the best appearance no horizontal joint should be more than 4 feet long, and several sizes of stones should be used. Broken-ashlar can be more quickly laid, and at less expense, if the stones are cut to certain heights in the yard, necessitating the cutting of one end joint only at the building.

The wall shown in Fig. 98 is made up of stones cut 4, 6, 8, 10, 12 and 14 inches in height, while in Fig. 99 only three sizes of stones

are shown. Fig. 98 shows the combination generally considered the more pleasing. In specifying broken-ashlar the height of the stones to be used should be specified. Broken-ashlar is sometimes

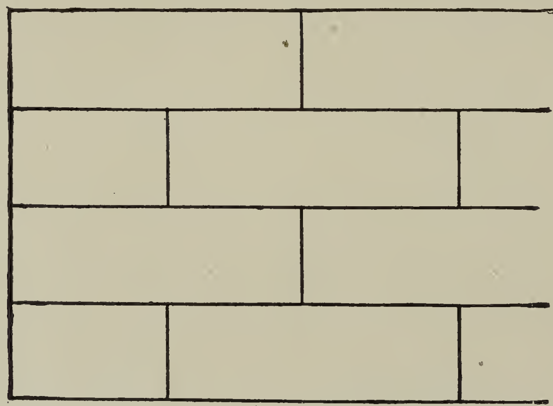


Fig. 96.—Coursed-ashlar Stonework. Regular Plumb Bond.

arranged in courses from 18 to 24 inches high, as in Fig. 101, when it is called random-coursed-ashlar. It looks very well in piers.

272. QUOINS AND JAMBS.—The stones at the corners of buildings are called the quoins, and these are often emphasized, as

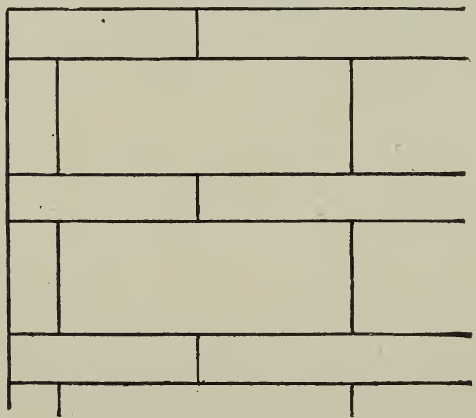


Fig. 97.—Coursed-ashlar Stonework. Regular-irregular Plumb Bond.

shown in Figs. 94 and 102. They should always be equal in size to the largest of the stones used in the wall. The stones at the sides of a door or window opening are called jambs. Fig. 103 represents

cut-stone window jambs in a rubble wall. A portion of the jamb-stones should extend through the wall to give a good bond.

In rubble walls the quoins and jambs are often built of brick, as shown in Fig. 95.

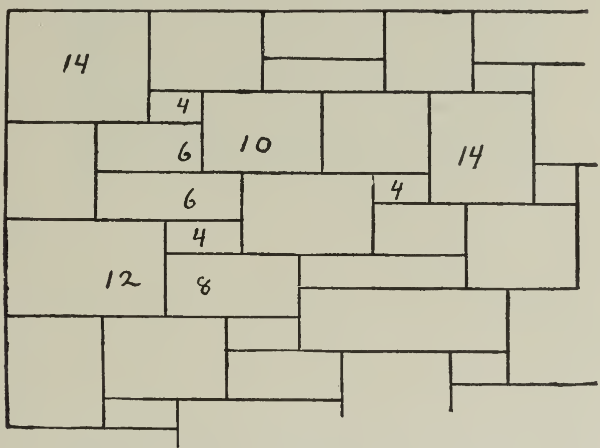


Fig. 98.—Broken-ashlar Stonework (Six Sizes).

All ashlar work should have the bed-joints perfectly straight and horizontal, and the vertical joints perfectly plumb, or the appearance will be greatly marred.

273. TRIMMINGS.—This term is generally used to denote all

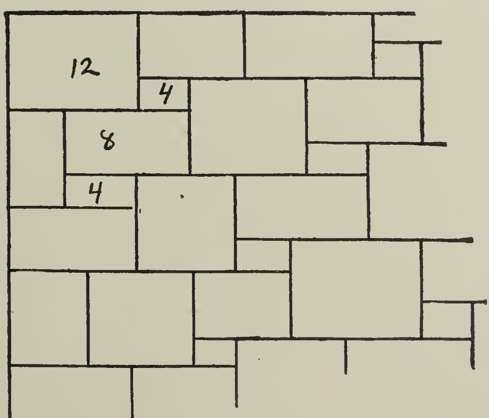


Fig. 99.—Broken-ashlar Stonework (Three Sizes).

moldings, caps, sills and other stonework, except ashlar. The trimmings may be pitched off on the face, but all washes, soffits and jambs should be cut or rubbed.

Fig. 100.—Broken-ashlar Stonework, Rock-face.

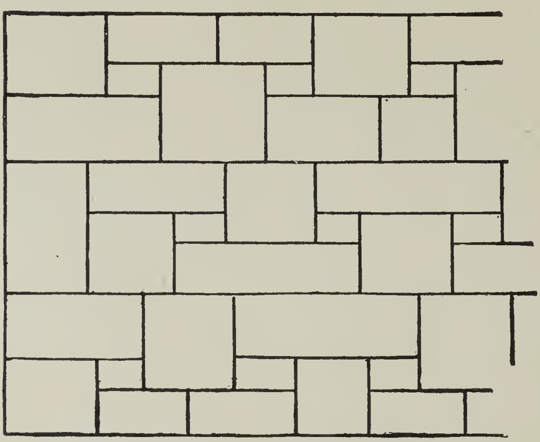


Fig. 101.—Random-coursed-ashlar Stonework.

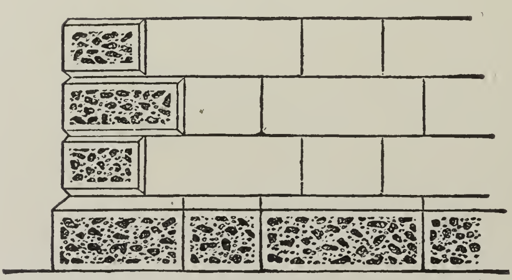


Fig. 102.—Regular-coursed-ashlar Stonework, Rustic Quoins and Plinth.

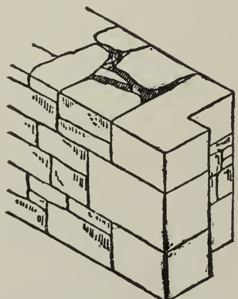


Fig. 103.—Cut-stone Window Jamb, Rubble Wall.

2. STONE-CUTTING AND FINISHING.

274. STONE-CUTTING TOOLS.—In order that the architect may specify correctly how he wishes the stone in his buildings finished, it is necessary for him to be familiar with the tools used in

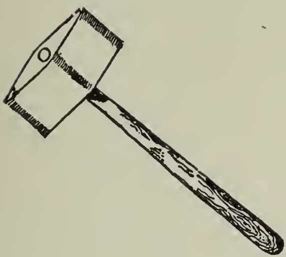


Fig. 104.—Axe or Pean-hammer.

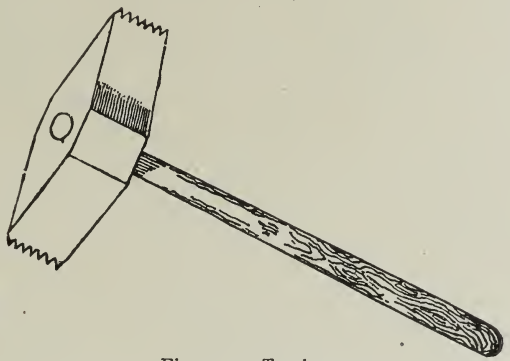


Fig. 105.—Tooth-axe.

cutting and with the technical names given to different kinds of finish.

There are several kinds of hammers used by masons in dressing

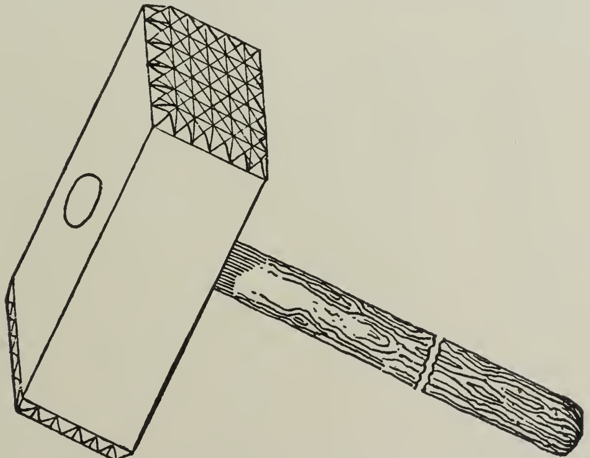


Fig. 106.—Bush-hammer.

rubble, and also a variety of tools used in quarrying, but as they are not used in working the finished stone they will not be described.

The Axe or Pean-hammer, Fig. 104, has two cutting-edges. It

is used for making drafts or margin-lines around the edges of the stones and for reducing the faces to a level. It is used after the point on granite and other hard stones.

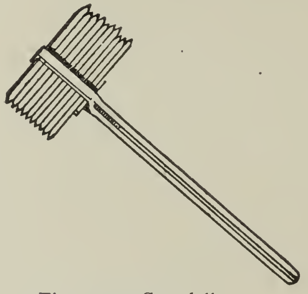


Fig. 107.—Crandall.

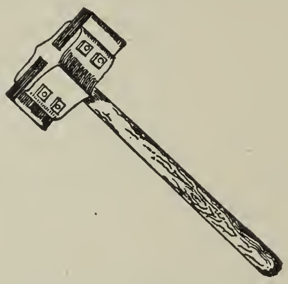


Fig. 108.—Patent-hammer.

The Tooth-axe, Fig. 105, has its cutting-edges divided into teeth, the number of which varies with the kind of work required. It is used for reducing the face of sandstones to a level, ready for the crandall or tool. It is not used on granites and hard stones.

The Bush-hammer, Fig. 106, is a square hammer, with its ends (from 2 to 4 inches square) cut into a number of pyramidal points. It is used for finishing the surface of the hardest sandstones and limestones, after the face of the stone has been brought nearly to the plane required.

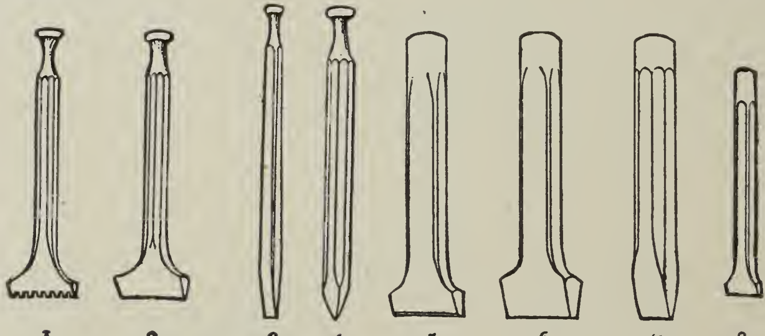


Fig. 109.—Chisels.

The Crandall, Fig. 107, is a malleable iron bar about 2 feet long, slightly flattened at one end, in which is a slot ⅜ of an inch wide and 3 inches long. Through this slot are passed ten double-headed points of ¼-inch square steel, about 9 inches long, which are held in place by a key. Only one end of the crandall is used, and as the points become dull they can be taken out and sharpened, or the

ends can be reversed. It is used for finishing sandstones after the surfaces have been prepared by the tooth-axe or chisel.

The Patent-hammer, Fig. 108, sometimes called the bush-hammer, is made of four, six, eight or ten thin blades of steel, ground to an edge and bolted together so as to form a single piece. It is used for finishing granite and hard limestones, the fineness of the finish being regulated by the number of blades used.

The Point, Fig. 109, No. 4, has a sharp point, and is used in breaking off the rough surfaces of the stones and reducing them to planes, ready for the axe, hammer or tool. It is also used to give a rough finish to stones for *broached* work and also for *picked* work. No. 1, Fig. 109, represents the *tooth-chisel,* used only on

Fig. 110.—Rock-faced or Pitch-faced Stone-pitching Chisel.

Fig. 111. — Rock-faced Stone with Draft-line or Margin.

soft stones; No. 2 a *drove,* about 2 or 3 inches wide; Nos. 3, 7 and 8 different forms of chisels used on soft stones. No. 5 is a *tool,* usually from 3½ to 4½ inches wide, used for finishing sandstones, and No. 6 is a pitching chisel, used as in Fig. 110.

275. DIFFERENT KINDS OF FINISH.—*Rock-faced or pitch-faced* work is shown in Fig. 110, the face of the stone being left rough as it comes from the quarry, with the joints or edges "pitched off" to a line as shown. The greatest projection of the face of the stone beyond the plane of the joints should be specified. The ashlar shown in Fig. 100 is "rock-faced."

Rock-faced work with margin or draft-lines is shown in Fig. 111. The margin (often called draft-line) is cut with a tool-chisel on soft stones and with an axe on granites. Sometimes only the angle of the quoins has a draft-line, as in Fig. 112, when it is called an "angle-draft." Rock-faced ashlar is naturally cheaper than any kind of dressed ashlar, particularly in granite.

Broached Work.—The surface of the stone is dressed off to a level surface, with continuous grooves made in it by the point. Fig. 113 shows a stone with margin or draft-lines and broached center.

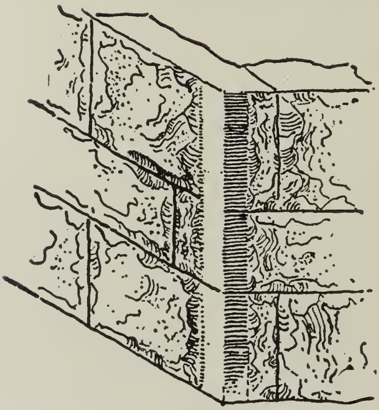


Fig. 112.—Rock-faced Stonework with Angle-draft.

Pointed Work (Figs. 114 and 115).—When it is desired to dress the face of a stone so that it will not project more than from ¼ to ½ an inch, and when a smooth finish is not required, as in basement piers, etc., the rock-face is taken off with a point and the surface is *rough-pointed* or *fine-pointed,* according as the point is used over every inch or half-inch of the stone. The point is used oftener for dressing hard stones than soft stones.

Tooth-chiselled Work. — The cheapest method of dressing soft stones is the one in which the tooth-chisel only is used. This gives a surface very much like pointed work, but usually it is not so regular. (See Fig. 109, 1.)

Tooled work is done with a flat chisel from 3½ to 4½ inches wide (see Fig. 109, 5), and the lines are continued clear across the width

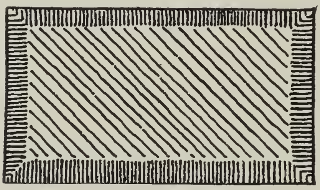


Fig. 113.—Broached Stone with Tooled Margin or Draft-line.

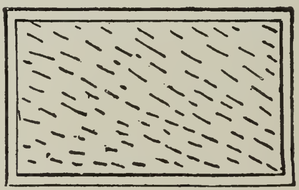


Fig. 114.—Rough-pointed Stone with Margin.

of the piece, as shown in Fig. 116. When well done it makes a very pretty finish for sandstones and limestones, and especially for molded work.

Drove work is much like tooled work, but is done with a chisel about 2½ inches wide and in rows lengthwise of the stone face, as shown in Fig. 117. Drove work does not take quite as much time as tooled work, and hence is cheaper; but it does not look so well. (See Fig. 109, 2.)

Bush-hammered Work.—This finish is made by pounding the surface of the stone with a bush-hammer, leaving it full of points, as in Fig. 120. It makes a very attractive finish for the harder kinds of sandstones and limestones, but ought not to be used on soft stones.

Crandalled Work (Fig. 118).—The face of the stone is dressed all over with the crandall, which gives it a fine pebbly appearance

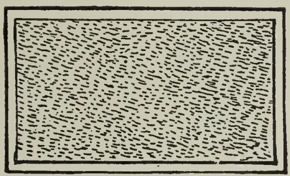


Fig. 115.—Fine-pointed Stone with Margin.

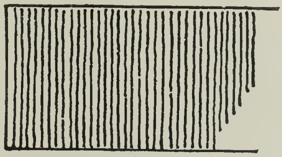


Fig. 116.—Tooled Stone.

when thoroughly done. It makes a sparkling surface for red sandstones, and in Massachusetts is used more than any other finish for sandstones. The crandall is not used on granites and other hard stones.

Rubbed Work.—One of the handsomest finishes for sandstones and limestones is obtained by rubbing their surfaces until they are perfectly smooth, either by hand, using a smooth piece of soft

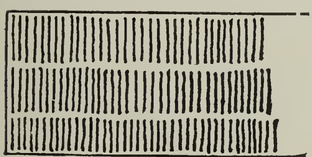


Fig. 117.—Drove Work on Stone.

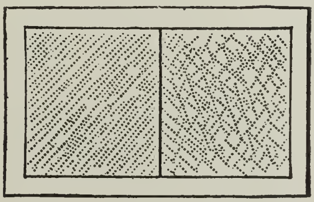


Fig. 118.—Crandalled Stone with Margin.

stone with water and sand for rubbing, or by laying the stones on a revolving bed called a rubbing-bed. When the stone is first sawed into slabs the rubbing is very easily and cheaply done, so that rubbed sandstone ashlar is often as cheap as rock-faced work in yards where steam saws are used. The saws leave the stone comparatively smooth and suitable for the top of copings and places which are not in view. Granite marbles and many limestones, when rubbed long enough, take a high polish.

Picked Work.—In this work the face of the stone is first levelled off with the point and then picked all over. Broken-ashlar finished in this way has a very pretty effect, but is quite expensive.

Patent-hammered or Bush-hammered Work (Fig. 119).—When it is desired to give a finished surface to granites and hard limestones they are first dressed to a rough surface with the point and then to a medium surface with the same tool, and finally finished with the patent-hammer. The fineness of the finish is determined by the

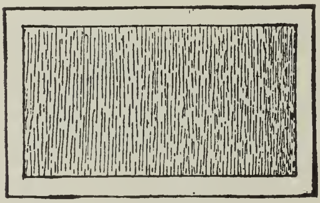


Fig. 119.—Patent-hammered Stone with Margin.

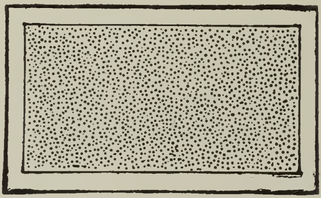


Fig. 120.—Bush-hammered Stone with Margin.

number of blades in the hammer, and the work is said to be "six-cut," "eight-cut" or "ten-cut," as six, eight or ten blades are used. Government work is generally ten-cut. Eight-cut is generally used for average work, and for steps and doorsills six-cut is sufficiently fine. The architect should always specify the number of blades to be used when the work is to be finished with a patent-hammer. The same finish may be obtained with the axe or pean-hammer, but it requires much more time.

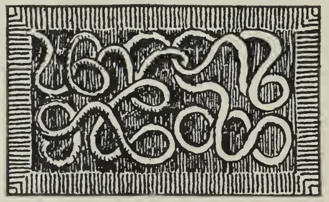


Fig. 121.—Vermiculated Work with Chiselled Margin.

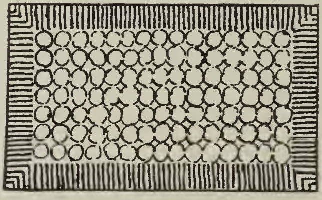


Fig. 122.—Fish-scale Work with Chiselled Margin.

Vermiculated Work (Fig. 121).—Stones dressed so as to have the appearance of having been worked by worms. This work is generally confined to quoins and base-courses.

Rusticated Work.—This term is now generally used to denote sunk or bevelled joints, as in Figs. 102 and 123, although it originally

referred to work honeycombed all over on the face to give a rough effect, as shown in Fig. 102.

Fish Scale or Hammered Brass Work (Fig. 122).—Work made to imitate hammered brass, and done with a tool with rounded corners.

Vermiculated and fish-scale work are seldom seen in this country.

276. LAYING OUT WORK.—If the cost of the stonework must be considered, the architect should ascertain from some reliable local stone-dealer the most economical size for the kind of stone he intends to use, and lay out his work accordingly.

3. MISCELLANEOUS CUT-STONE TRIMMINGS.

277. CUT-STONE TRIMMINGS IN BRICK BUILDINGS.—If the stonework consists merely of trimmings for a brick building, the architect or his draughtsman must first ascertain the exact measurement of the bricks as laid in the wall, and the stones must be figured so as to exactly fit in with the brickwork; otherwise the

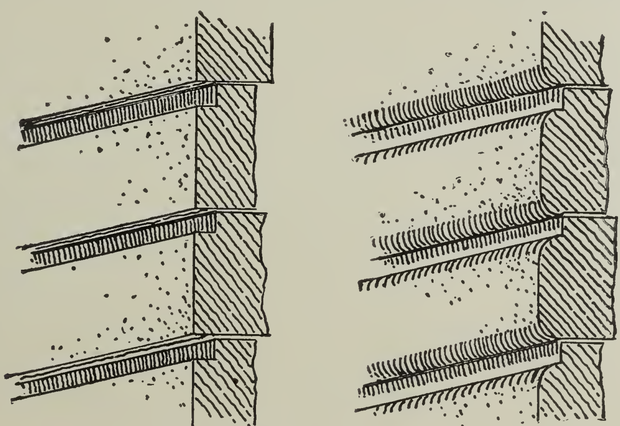


Fig. 123.—Rusticated Joints in Ashlar Stonework.

bricks will have to be split where they come against the stones, thereby greatly marring the looks of the building. Bond-stones and belt-courses built into a pier must conform exactly to the size of the pier. As it is seldom that the bricks from any two yards are of exactly the same size, the exact size of the bricks that are to be used must be taken, as even a variation of ¼ of an inch often makes bad work.

278. DRIPS.—Projecting cornices, belt-courses and other trimmings should have depth enough to *balance on the wall,* and all pro-

jecting stones should have a *drip* as near the top of the stone as possible, to prevent the water from dripping over the rest of the moldings and down on the wall. Thus in a cornice such as shown in Fig. 124 the stone should be cut at a sharp angle at *A*, so that some of the water will drop off, and there should be a regular drip at *B*, so that the water will not run down on the wall. It is a good idea to cut a drip in all window sills, as shown in Fig. 125. In the

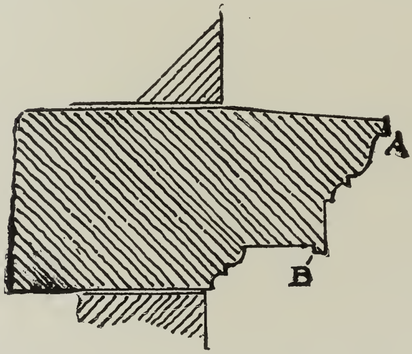


Fig. 124.—Stone Cornice with Drip and Wash.

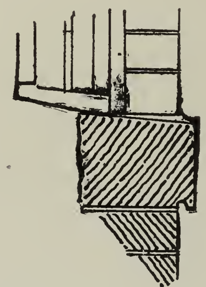


Fig. 125.—Stone Window Sill with Drip and Wash.

summer dust always lodges on sills and projecting ledges, and when it rains the water washes the dust, which often contains cinders, over the face of the stonework and down on the wall, causing both to become streaked and unsightly.

The architect will find that if he is careful to provide drips on all moldings and sills his buildings will remain bright and clean for a

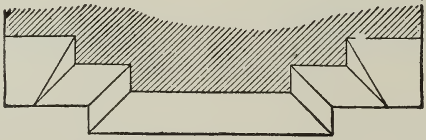


Fig. 126.—Top of Stone Belt-course Around Pilaster.

much longer time than would otherwise be the case. Some think it is even better to slightly change the profile of the molding if necessary, in order to provide a drip, as the most beautiful molding looks unsightly when streaked and stained with dirty water.

279. WASHES.—The top surfaces of all cornices, belt-courses, capitals, etc., should be cut so as to pitch outward from the wall line, as shown in Fig. 124. If the top is left level, the rain water falling upon it will, in time, disintegrate the mortar in the joint above and

finally penetrate into the wall. Surfaces bevelled in this way are called washes.

When the face of the wall is broken with pilasters, or the windows

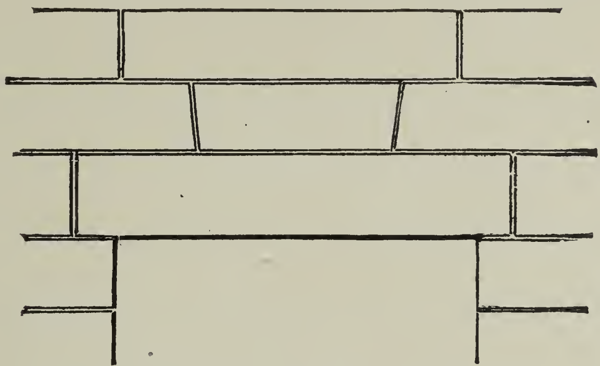


Fig. 127.—Stone Ashlar Cut to Relieve Lintel or Cap.

are recessed, the wash on the belt-courses should be cut to fit the plan of the wall above, as shown in Fig. 126.

280. STONE RELIEVING AND SUPPORTING LINTELS. —A stone lintel is a stone which covers a door opening or window opening, and which, therefore, acts as a beam. It is often called by stonecutters a "cap." When it is necessary to use a rather long lintel in a stone wall the ashlar above the lintel may be arranged so as to relieve the lintel of some of the weight, as shown in Fig. 127. If the wall above the lintel is of brick a relieving-arch may be turned; but this generally detracts from the appearance of the building, and the best way to strengthen the lintel, when the length does not exceed 6 feet, is to let it rest on a steel angle-bar the full length of the cap, as shown in Fig. 128. When the width of the opening is more than 6 feet the lintel should be supported by steel beams, as shown in Figs. 129 and 130. A single beam, as in Fig. 129, may be used where only the weight of the lintel and its load is to be supported, and two or more beams where the whole thickness of the wall and also the floor joists must be supported.

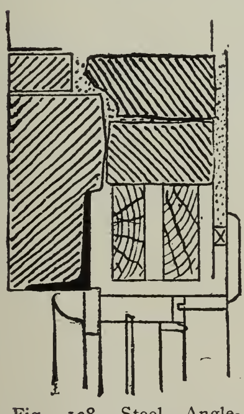


Fig. 128.—Steel Angle-bar, Full Length of Stone Cap. Cap Less Than Six Feet Long.

When the lintel is the full thickness of the wall, and steel sup-

ports are undesirable, the *strength* of the lintel may be increased, when it is a stratified stone, by cutting it so that the layers are on edge, like a number of planks placed side by side. The Greeks and Romans often cut their lintels in this way, and apparently for this reason. The resistance to weathering, however, is decreased by this method of cutting and setting.

In locating windows in a brick or stone wall the designer should be careful to arrange them so that they will not come under a pier. This is not apt to happen in the front of a building, but it sometimes happens in the side or rear walls, where the windows are placed to suit the interior arrangement and without regard to the external effect.

If a door or window must be placed under a pier, steel beams should be used to support the wall above and also the lintel. Many

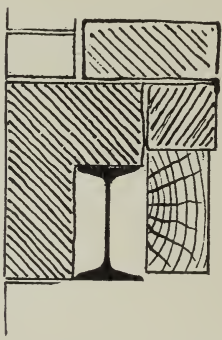


Fig. 129.—One I-Beam Supporting Stone Lintel and Its Load.

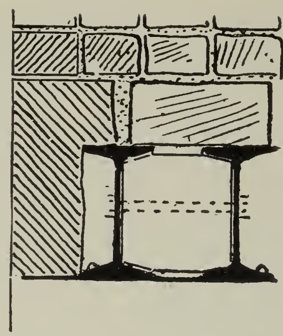


Fig. 130.—Two I-Beams Supporting Stone Lintel, Wall and Joists; Three-eighths-inch Steel Plate Rivetted to Beams.

broken lintels are evidences of a too frequent neglect of this precaution.

Another detail that should be carefully considered in laying out the stonework is the building of the ends of caps and sills into the piers. If a pier extends through several stories all the joints will be slightly compressed and the masonry will settle slightly; and if the ends of the caps and sills of the adjoining windows are built solidly into the piers they are very apt to be broken as the piers settle.

It is better to keep the caps and sills back from the face of a pier, and either to build pilasters against it to receive the caps and sills, as shown at *A,* Fig. 131, or to build the ends of the stones into

it in such a way that they can give a little. When these stones are back from the face of a pier this can easily be done.

Lintels should have a bearing at each end of from 4 to 6 inches, according to the width of the opening. It is better not to build the ends into the wall further than necessary to give a sufficient bearing.

281. COMPOSITE STONE LINTELS.—Designs sometimes require a stone lintel over a store window 10 to 12 feet wide. To procure such a lintel in one piece is, in many places, impracticable,

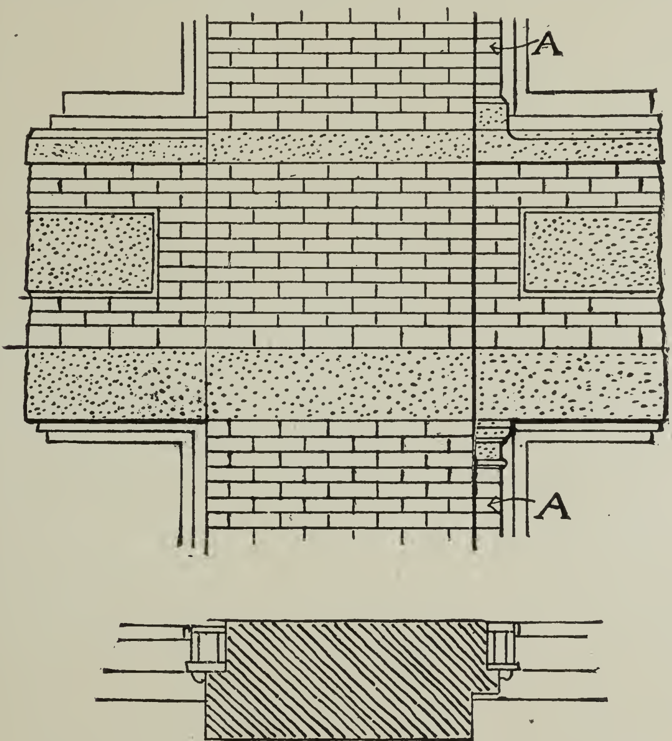


Fig. 131.—Pilasters Against Pier to Receive Stone Caps and Sills.

and it is therefore necessary to build up the lintel in pieces. When such is the case three stones at least should be used, and the end joints should be cut as shown in Fig. 132. Stones cut in this way are bound together better, and also appear to be self-supporting. A greater number of stones, usually five or seven, may be used if preferred, but the joints should be cut in the same way. Such lintels should always be supported by steel beams, as shown in Figs. 129 and 130.

282. STONE SILLS.—A stone "sill" is a piece of stone placed at the bottom of a window opening in a stone or brick wall. Door-steps or thresholds also are often called "sills."

A *slip sill* is a sill that is just the width of the opening, and is not built into the walls at the jambs.

A *lug sill* is a sill that has *flat* ends, built into the walls, as shown in Fig. 133.

All sills should be cut with a wash of at least from ½ an inch to 5

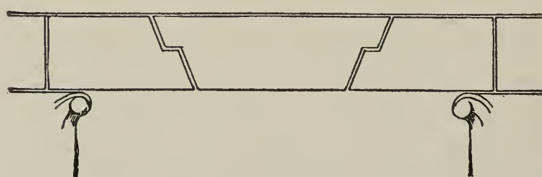


Fig. 132.—Composite Stone Lintel. Openings 10 or 12 Feet Wide. Always with Steel Supports.

inches in depth, and if the ends are to be built into the wall they should be cut as shown in Fig. 133. In some parts of the country each sill is cut with a straight bevelled surface the full length of the stone, and when it is built into the wall the bricks are cut to fit it. This is not a good method, as the water running down the jamb and striking the sill is apt to enter the joint between the bricks and stone, and the slanting surface offers an insecure bearing for the bricks.

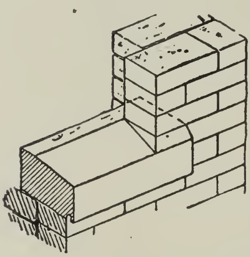


Fig. 133.—Stone Lug Sill Showing Flat Ends, Wash and Drip.

Slip sills are cheaper than lug sills, but they do not look so well; and there is also danger of the mortar in the end joints being washed out in time.

Slip sills, however, are not likely to be broken by any settlement in the brickwork, and for this reason many architects prefer to use them for the lower openings in heavy buildings and also for very wide openings.

Lug sills should be built not more than 4 inches into the jambs, and should be bedded only at the ends when setting.

283. CUT-STONE ARCHES. NAMES OF VARIOUS PARTS.—Figure 134, "Cut-stone Arch and Vault with Names of the Various Parts of the Arch," illustrates the different constructional divisions of this kind of masonry.

In stone-cutting the following terms also are often used for the different parts of arches and vaults:

The Soffit.—The concave surface of the arch.

The Back.—The convex surface of the arch.

The Spandrel filling.—The filling in the triangular spaces above the voussoirs and between the springers and the crown.

A Ring-course.—A course of stones parallel to the voussoirs.

The Arch-ring.—The voussoirs, taken together.

284. STONE ARCHES. GENERAL DETAILS.—Stone arches are very frequently used in both stone and brick buildings.

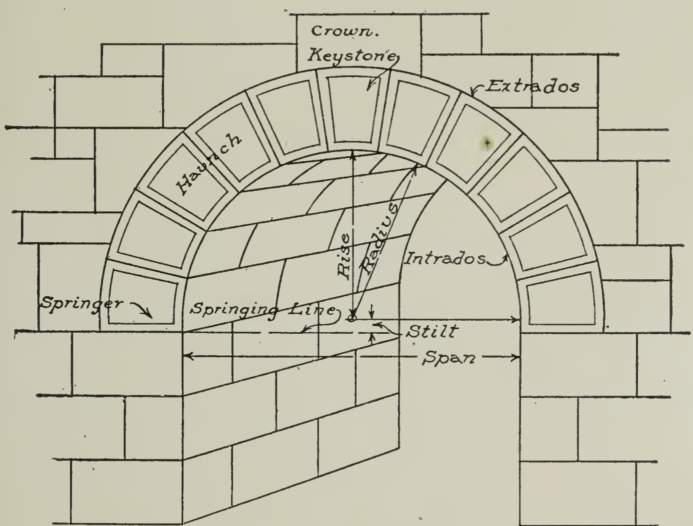


Fig. 134.—Cut-stone Arch and Vault with Names of Various Parts of the Arch.

They may be built in a great variety of styles, and with either circular, elliptical or pointed soffits. The method of calculating the stability of a stone arch is the same as for a brick arch; but since a stone arch is constructed of larger pieces, the mortar in the joints adds very little, if anything, to its stability, and a stone arch of the same size as a brick arch is rather more liable to settle or crack than the latter, and should be constructed with greater care. The method of calculating the stability of arches is given in Chapter VIII of the "Architect's and Builder's Pocket-Book." In block stone arches each block, or "voussoir," should always be cut wedge-shape and exactly fitted to the place it is to occupy in the arch. The joints between the voussoirs should be of equal width the entire depth

and thickness of the arch, in order that the bearing may be uniform over the entire surface. The thickness of the joints will depend somewhat upon the character of the stonework. In finely dressed work $\frac{3}{16}$ of an inch is the usual thickness, while in rock-faced work they are seldom made less than $\frac{3}{8}$ of an inch. One-

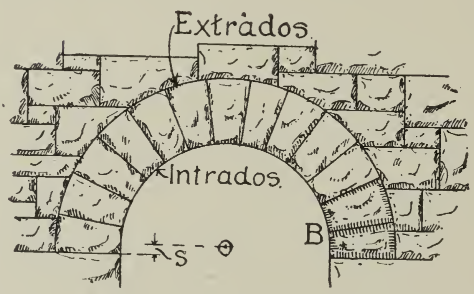


Fig. 135.—Common Semi-circular Stilted Stone Arch.

fourth of an inch, however, is all that should be allowed in first-class work.

The joints should also radiate from the center from which the intrados is struck, or, in the case of an elliptical arch, they should be at right-angles to a tangent drawn to the intrados at that point. (See Fig. 140, Article 290.)

The back of the arch may be either concentric with the intrados, or the ring may be deeper in the center than at the sides.

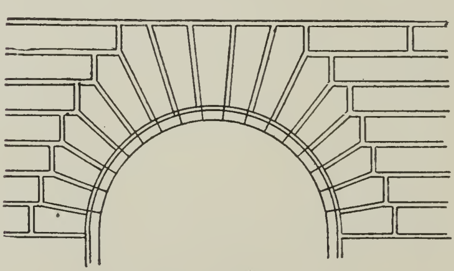


Fig. 136.—Semi-circular Stone Arch. Voussoirs Cut to Bond with Coursed-ashlar.

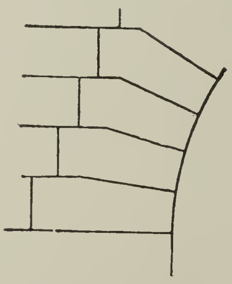


Fig. 137. — Stone Voussoirs Bonding with Coursed-ashlar.

The most common stone arch is that shown in Fig. 135, the arch ring being of equal depth and the voussoirs all of the same size, and rock-faced with pitched joints. Occasionally the voussoirs are cut with a narrow margin draft, as shown at B. When the spring-

ing line of an arch is below the center, as shown in Fig. 135, the arch is said to be "stilted," the distance S being called the "stilt." Stilted arches are very common in Romanesque architecture.

A semi-circular arch is one of the best shapes for supporting a wall. It must, however, have sufficient abutments, and the depth of the arch-ring, or the normal distance in feet from the intrados to the extrados should be equal to at least

$$0.2 + \frac{\sqrt{\text{radius} + \text{half span}}}{4}$$

Arches used in connection with coursed-ashlar, especially in Renaissance buildings, often have the voussoirs cut to the shapes shown in Figs. 136 and 137.

Such arches are of course more expensive than arches with the

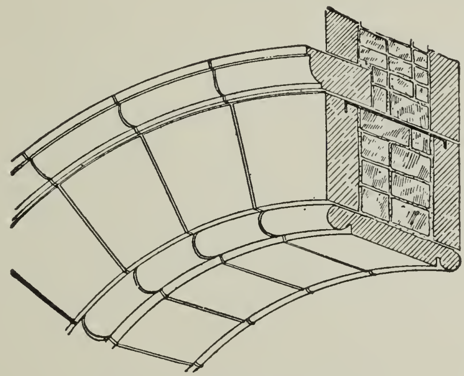


Fig. 138.—Built-up Stone Arch.

intrados and extrados concentric, as there is more waste to the stone, and more patterns are required. They have a more pleasing appearance, however, and are also stronger. Voussoirs of the shape shown in Fig. 137 must be cut with extreme accuracy.

In dividing an arch into voussoirs it should be remembered that, as a rule, narrow voussoirs are more economical of material, but more expensive in point of labor.

In most arches the width of the voussoirs at the bottom is about three-eighths of the width of the ring, although it may vary from one-fourth to one-half.

Two voussoirs are cut very often from one stone, with a false joint cut in the center. This is done generally for economy, although

in some cases it may add to the stability of the arch. The arch is generally divided into an uneven number of voussoirs, so as to have a keystone, the voussoirs being laid from each side and the keystone exactly fitted after the other stones are set. There appears to be no necessity of having a keystone, and the author has been informed that Sir Gilbert Scott always used an even number of voussoirs, believing that thereby there is less danger of the voussoirs cracking.

285. LABEL-MOLDINGS ON STONE ARCHES.—In nearly all styles of architecture the better class of buildings have the arch-ring molded. In Gothic and Romanesque work a projecting molding called a "label-mold" is generally placed at the back of the arch. When not very large it may be cut on the voussoirs, but usually it is made a separate course of stone, as shown in Fig. 138.

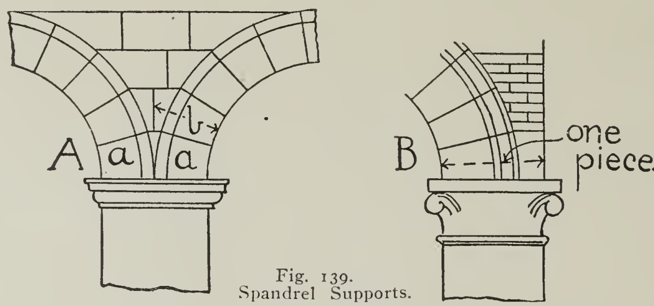


Fig. 139.
Spandrel Supports.
A. One Springing Stone for Two Arches. B. Lower Voussoir of Stone Arch Cut Full Width of Pier.

When this is the case the depth of the arch-ring without the label-mold should be sufficient for stability. The label-mold may be cut into pieces of the same length as the voussoirs, or the joints may be made independent of those in the arch.

286. BUILT-UP STONE ARCHES.—Large arches, especially those which show on both sides of the wall, are often, for the sake of economy, built of several courses of stone, jointed so as to have the appearance of solid voussoirs. Fig. 138 shows the manner in which many of the large arches designed by the late H. H. Richardson were constructed. Every alternate pair of voussoirs should be tied together by galvanized-iron clamps.

287. BACKING OF STONE ARCHES.—The arches generally seen in the fronts of buildings are usually only about 6 inches thick, and are backed with brick arches. The brick arches should be of the same shape as the stone arches, and the bricks should be laid

in cement mortar, so that there may be no settlement in the joints. The backing should be well tied to the stonework by galvanized-iron clamps.

288. RELIEVING-BEAMS OVER STONE ARCHES.—Very often arches are used for effect in places where sufficient abutments cannot be provided to resist the thrust. In such cases one or more steel beams should be placed in the wall just above the arches, with the ends resting over the vertical supports and an empty joint left under the middle part of the beams. The wall above can then be built on these beams, leaving the arches with nothing but their own weight to support. The additional weight which the beams carry to the abutments also greatly increases the latter's resistance to a horizontal thrust. The beams should be provided with anchors at their ends, with long vertical rods passing through them, to tie the different parts of the wall together.

Wherever segmental arches are used it is always a safe precaution to place steel rods back of them to take up the thrust, especially while the mortar in the abutments is green.

289. SUPPORT FOR SPANDRELS OF STONE ARCHES.—Wherever arches are used in groups care must be exercised in laying out the springing stones to give a level support for the spandrels. Thus where two arches come together, as at *A*, Fig. 139, if the first voussoir is cut in the shape of the arch on the back a small wedge-shaped piece of stone will be required to fill the space between the first pair of voussoirs. The weight of the wall above coming on this wedge might be sufficient to force the voussoirs in, seriously mar the appearance of the arch and cause cracks in the ashlar above. This danger may be overcome by cutting the lower stone, *a, a,* in one piece for both arches and extending the voussoir, *B*, to a vertical joint over the middle of the pier. This gives a level bearing for the lower stone in the spandrel and effectually prevents any pushing in of the voussoirs.

Another case very similar to this often occurs where the back of an arch comes almost to the corner of the wall or projection, as shown at *B*. If the distance between the back of the arch and the angle of the wall is less than 8 inches the lower voussoir should be cut the full width of the pier, as shown in the illustration.

290. ELLIPTICAL STONE ARCHES.—Arches built either in the form of an ellipse or oval, or pointed at the crown and elliptical

at the springing, are often used for architectural effect in buildings, although very seldom in engineering works. Such arches are very liable either to open at the crown and "kick up" at the haunches, or to fail by the middle voussoirs being forced down. An elliptical arch, especially if very flat, is undesirable for spans of over 8 feet, and should never be used without ample abutments unless beams are placed above the arch as described in Article 288.

The joints of an elliptical arch should be exactly normal (at right angles) to the curve of the soffit. If the line of the soffit is not a true ellipse, but is made up of circular arcs of different radii, the joints in each portion of the arch should radiate from the corresponding center. Fig. 140 shows an easy method for laying out the joints where the curve of the soffit is a true ellipse. Let M_1, M_2, M_3, etc.,

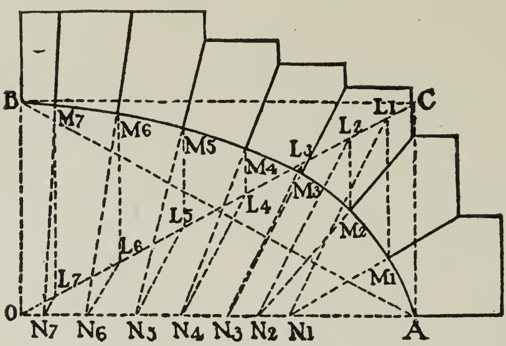


Fig. 140.—Method of Laying Out Joints of Elliptical Stone Arch.

be points on the ellipse from which it is desired to draw the joints. Draw tangents to the ellipse at the points A and B intersecting at C. Draw lines AB and OC. Draw lines from M_1, M_2, M_3, etc., perpendicular to OA and intersecting OC at L_1, L_2, L_3, etc. From these points draw lines perpendicular to AB, intersecting OA at N_1, N_2, N_3, etc. Lines drawn through N_1M_1, N_2M_2, etc., will then be normal to the curve and give the joints desired.

291. GENERAL CONSTRUCTION OF A THREE-CENTERED ARCH.—When the rise is to be not less than one-third the span, a three-centered arch is usually considered to give a curve more pleasing to the eye than one of a greater number of centers.

Fig. 141, "Cut-stone Elliptical Three-centered Arch," indicates the general method of drawing a three-centered curve for an arch, when the two centers of the shorter radii are on the springing line AB.

On the span *AB* and on the rise *HF* are set off *AD* and *FE* respectively, these distances being equal to each other, and less than the rise *HF*. *DE* is drawn, and is bisected by the perpendicular *CG* which is produced to intersect *FH* at *C*. Then will *C* and *D* be two of the required centers, the third center being found on *HB* at a distance to the right of *H* equal to *HD*.

An infinite number of curves may thus be constructed for the same span and rise.

292. CUT-STONE FOUR-CENTERED TUDOR ARCH.—The curve for this arch is shown in Fig 142, and may be constructed as follows: Divide the span *AD* into four equal parts, *AB, BO, OC* and *CD*. From *B* and *C* as centers, and with radii

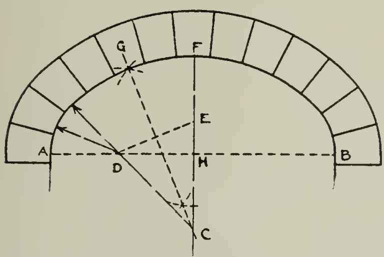


Fig. 141.—Cut-stone Elliptical Three-centered Arch.

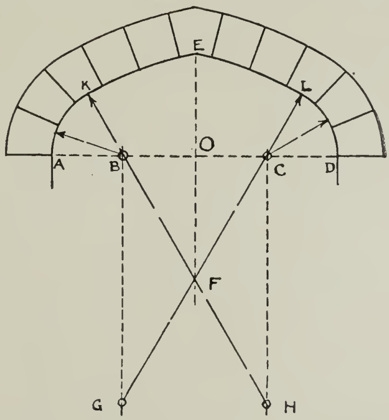


Fig. 142.—Cut-stone Four-centered Tudor Arch.

equal to *BC*, describe arcs intersecting at *F*. Draw *BF* and produce it to meet a perpendicular to *AD* drawn through *C*; and draw *CF* and produce it to meet a perpendicular to *AD* drawn through *B*. With *B* as a center and with a radius *AB* describe the arc *AK*, and with *C* as a center and with a radius *DC* describe the arc *DL*. Then with *H* as a center and with a radius *HK* describe the arc *KE*, and with *G* as a center and with a radius *GL* describe the arc *LE*.

293. CUT-STONE GOTHIC OR POINTED ARCH.—Fig. 143 illustrates the general form of one of these arches. In this particular example the lines of the intrados and extrados are concentric, and the arch is, as it were, circumscribed or built around an equilateral triangle, each side of which is equal in length to the span.

In this illustration *BB* is the springing line, and *A* is in each case the center from which the curve of the intrados of the arch-ring is drawn, *AC* being the radius and equal to the span.

Pointed arches are constructed of many different proportions, by taking different positions for these centers, and different lengths for the radii.

294. CUT-STONE SEGMENTAL ARCH.—Fig. 144 illustrates the general form of a segmental arch, which frequently replaces the full-centered or semi-circular arch because of limited space for rise. It is often used to span openings over doors and windows. Its construction is simple and is shown in the figure with

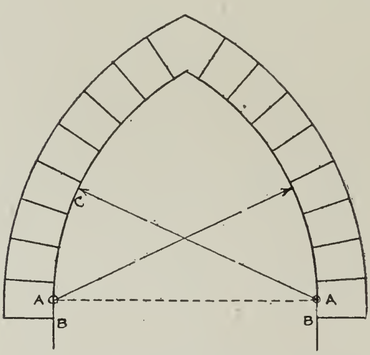


Fig. 143.—Cut-stone Gothic or Pointed Arch.

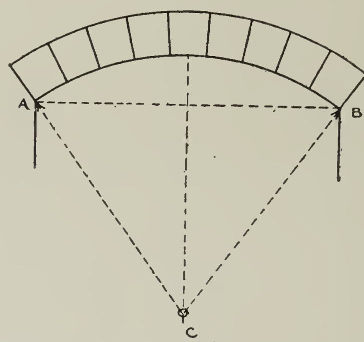


Fig. 144.—Cut-stone Segmental Arch.

its intrados curve described with *C* as a center and with *CA* equal to *CB* equal to *AB* the span, as a radius.

295. FLAT STONE ARCHES.—Shallow flat arches of stone, although somewhat pleasing to the eye, are very objectionable constructionally. If a flat arch must be used, to be self-supporting it should be of such height that a segmental arch of proper size can be drawn on its face, as indicated by the dotted lines in Fig. 145. Even then it is desirable to drop the keystone about 1 inch below the soffit line, so as to wedge the voussoirs tightly together. An arch such as is shown in Fig. 145 might be safely used for a span of 5 feet, but with greater caution for larger spans. The strength of such an arch may be increased by making "joggled" joints, that is, by notching one stone into the other, as shown by the dotted lines at *a*. Such joints, however, are quite expensive.

A very shallow flat arch, such as is shown in Fig. 146, should be cut out of one piece of stone, so as to be in reality a lintel with false

joints cut on its face. The ends of the lintel should have a bearing on the wall of 6 inches, as shown by the dotted lines, the face being cut away for about 2 inches in depth and veneered with brick. If this method is too expensive the lintel might be cut in three pieces and supported by a heavy angle-bar, as shown in Fig. 128.

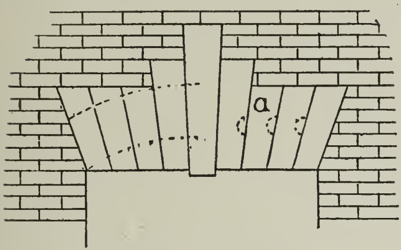


Fig. 145.—Flat Stone Arch, Joggled Joints.

Very long lintels are often made in the form of a flat arch (see Article 281), but are, or should be, always supported by steel beams or bars.

296. FLAT ARCH VOUSSOIRS WITH VERTICAL FACE JOINTS.—Built-up lintels and flat arches of stone are sometimes constructed with voussoirs which are cut as shown in Fig. 147. Here the face joints are vertical on both faces of the arch, but the arch principle is carried out by forming the joint vertically on only about 4 inches of the voussoirs back from each face of the arch-ring, and by cutting the joints sloping in the interior as shown.

In case only one face of the arch ring is seen, the sloping joints may extend back through the voussoirs to the back face.

297. RUBBLE-STONE ARCHES.—Arches are sometimes built of rubble stones. The stones should be long and narrow and roughly dressed to a wedge shape. They should be built with cement

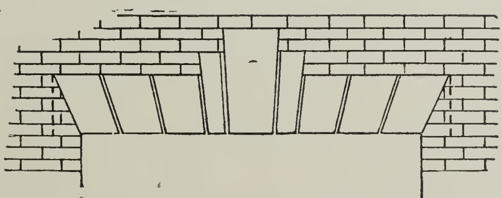


Fig. 146.—Shallow Flat Stone Arch in One Piece. A Lintel. False Joints.

mortar, as they depend largely upon the strength of the mortar for their stability.

298. CENTERS FOR ARCHES.—Every arch, whether of stone or brick, should be built on a wooden center made to exactly fit the curve of the arch and carefully set in place. The center should have ample strength to support the weight of the arch and much of the wall above, as it is undesirable to put any weight on the arch until

the mortar in the joints has become hard. A center is usually made with two ribs cut out of plank and securely spiked together, and the bearing surface formed of cross pieces about 1 by 2 inches in size nailed to the top of the ribs, as shown in Fig. 148. The ribs forming the supports for the cross pieces should be placed under each edge of the arch, and if the depth of the arch exceeds 12 inches three

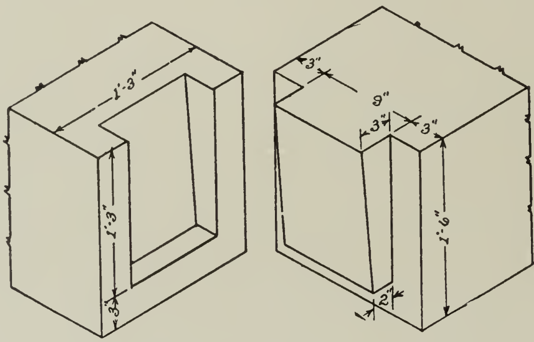


Fig. 147.—Stone Voussoirs for Flat Arch. Vertical Face Joints. Sloping Interior Joints.

ribs should be used. The center should be supported on wooden posts resting on blocks set on the sill or some sufficient support below. It should not be removed until the mortar in the arch joints has had ample time to set.

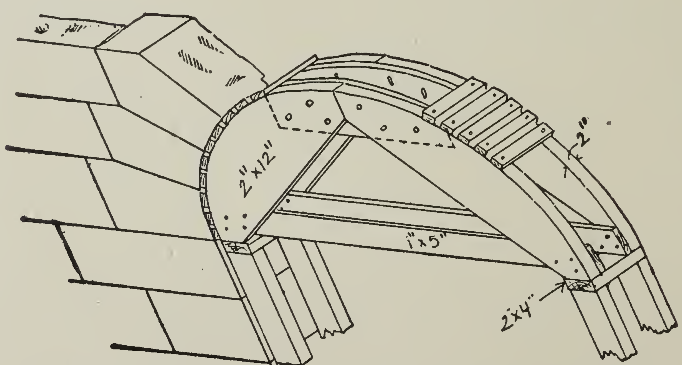


Fig. 148.—Wooden Center for Stone Arch. Usual Construction.

Centers for spans of considerable width are framed together with heavier timbers and in a variety of ways. The general method is shown in Fig. 149, which represents a center for a 10-feet span.

The framework, indicated by the straight pieces, is made of 6 by 6 or 4 by 8 timbers, and to these are spiked pieces of plank cut to the

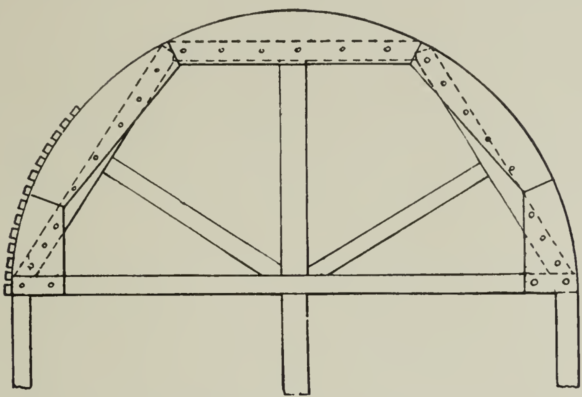


Fig. 149.—Wooden Center for Stone Arch. Construction for Spans of Ten Feet and Over.

outline of the arch. The cross pieces are then nailed to the top edge of the planks, as in Fig. 148. Such a center should have a support under the middle as well as at the sides. As the centers are only required for temporary use, architects generally allow the carpenter to construct them as he deems best, but the superintendent should satisfy himself that they are of ample strength and well supported before the masons commence building the arch.

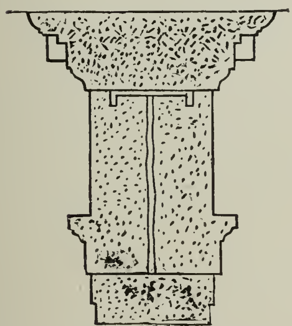


Fig. 150.—Common Method of Building Up Parts of Stone Entablature.

299. COLUMNS.—Stone columns not exceeding 8 feet in height usually have the shaft cut in one piece and the caps and bases in separate pieces. For columns of great height it is generally necessary to build the shaft of several pieces. The joints between the cap and base and the shaft, and between the different stones of the shaft, should be dressed exactly normal to the axis of the column and to a true plane, so that the pressure will be evenly distributed over the whole area of the joint. Nothing but cement mortar should be used in these joints, and their outer parts for ¾ of an inch back from the face should be left empty to prevent the outer edges of the stones from chipping off.

If a column is built against a wall, the pieces from which the cap and base are cut should either extend into the wall or be secured to it by galvanized-iron clamps.

300. ENTABLATURES.—Stone entablatures spanning porch openings, etc., may be cut from one piece of stone, or, if of considerable height, may be built up with several horizontal courses.

Fig. 150 shows a common method of building up the lower parts of an entablature, the corona and facia being in still another course above those shown. When jointed as in the figure the bottom joint

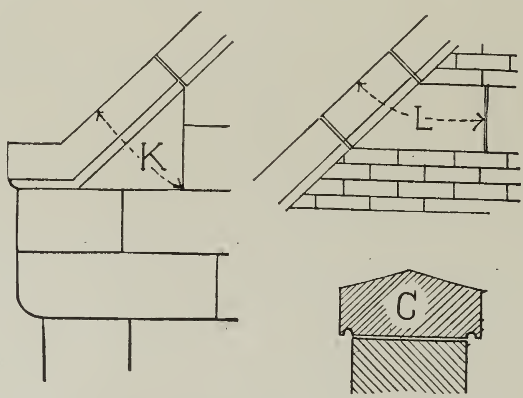


Fig. 151.—Stone Copings. K. Gable Coping Kneeler. L. Gable Coping Bond Stone. C. Horizontal Coping with Drip and Weathering.

should not be filled with mortar except at the ends, near the bearings.

The various stones composing the cornice, frieze and architrave should be well tied together with iron clamps, especially at all external corners. It is a good idea also to tie the cornices of porches to the building by long rods built inside the masonwork to prevent the porches from "pulling away" from the walls.

301. STONE COPINGS.—All walls not covered by the roof should be capped with wide stones called the copings. Horizontal copings should be weathered on top and should have drips at the bottom edges, as shown in drawing *C*, Fig. 151. The width of the coping should be about 3 inches greater than that of the wall.

Gable copings do not require weathering, but they should project about 1½ inches from the face of the wall, and should have sharp outer edges, so that the water will not run in against the wall. As the weight of a sloping coping tends to cause it to slide on the wall, the coping should be well anchored, either by bonding

some of the stones into the wall, or by using long iron anchors. The bottom stone, sometimes called the "kneeler," should always be well bonded into the wall and cut with a horizontal bed-joint, as shown at *K*, Fig. 151. About once in every 6 feet in height a short piece of coping should be cut so as to bond into the wall, as at *L*. Gable copings sometimes have the part which rests on the wall cut in steps, so that each stone has a horizontal bearing. This method, however, is very expensive, unless the coping is cut in very short pieces; and this is objectionable on account of the number of joints required.

As a rule, copings should be designed with as long stones as possible to decrease the number of joints and the admission of

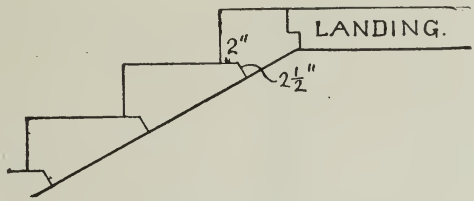


Fig. 152.—Stone Stairs and Landing.

moisture. Horizontal coping stones are often clamped together at their ends to prevent their getting out of place sideways.

302. STONE STEPS AND STAIRS.—These should always be built of some hard stone, preferably granite, and should have solid bearings. Outside steps generally rest on a wall at each end, and if more than 6 feet long should have a support in the middle. Each step should have a bearing of at least 1½ inches on the back part of the one below. Steps to outside entrances should pitch outward about ⅛ of an inch Steps are much easier to use when cut with nosings; but owing to the increased expense they are used only in costly buildings.

Stone stairs may be built with one end only supported. In European buildings, and in many of our Government buildings, the stairs are constructed as shown in Fig. 152, either with or without nosings. One end of each step is built solidly into the wall, and each step is supported by the one below, owing to the way in which they are cut. The bearing of one step on another should be not less than that shown in the figure. The bottom step, obviously, must be well supported its full length, as it has to sustain nearly the full weight of the

stairs. The steps are usually cut with a triangular cross-section as shown, as this shape is less expensive and reduces the weight, besides giving a pleasing appearance from below.

The railing, posts and balusters are generally of iron, and the latter are dowelled into the ends of the steps.

The laying out and detailing of other stone trimmings are governed by the principles above noted.

303. CIRCULAR STAIRS IN STONE.—Circular stairs in stone may be constructed in either one of two ways. The steps may be "hanging steps" which converge toward a well-hole, the outer ends of the steps being built into the outside walls, or they may be

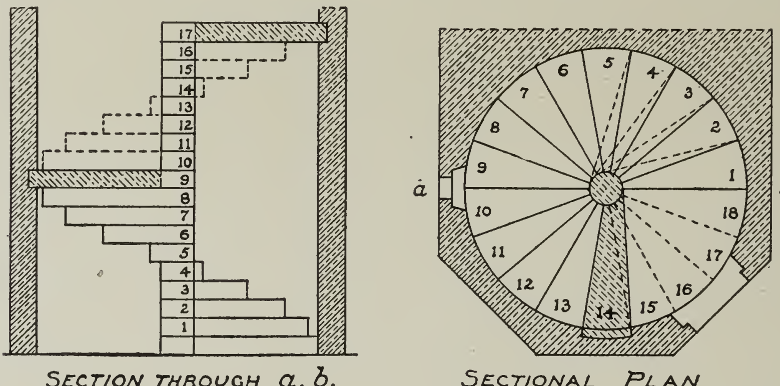


Fig. 153.—Circular Stone Stairs.

supported at both ends, by the outside walls and by a central newel.

A variation of the latter, and a very common construction, especially for circular staircases of small diameter, is shown in Fig. 153.

Each step is cut out in the form indicated, with a circular portion on the inner end having a diameter equal to that of the intended newel.

304. BOND-STONES AND STONE TEMPLATES.—The building regulations of certain cities require that bond-stones shall be used in brick piers of less than a certain size. When such stones are used they should be of some strong variety, and should be cut the full size of the pier. It is also very important that the outside and inside bricks be brought exactly to the same level to receive the stones; for if the latter bear on the outside bricks only, the weight

will cause these bricks to buckle and separate from the pier, while if the weight is borne by the middle part, the pier is liable to crack through at that point.

Bond-stones should not be used in a wall in the manner shown in Fig. 154, as they prevent any spreading of the pressure, and keep concentrating it back to that part of the wall which is immediately under the bond-stones, as shown by the short vertical lines.

Bearing-stones used under the ends of beams or girders, to distribute the weight along the walls, are called *templates*. They should always be very hard, strong stones, laminated if possible; and the thickness of each stone should be one-third of its narrowest dimension, unless the stone is large, but in no case less than 4 inches. It is always better to have templates too large than too small.

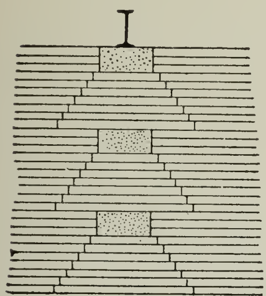


Fig. 154.—Bond-stones and Template in Brick Wall. Incorrect Method of Construction.

The bearing surface of the templates should be such that the pressure which it transmits to the wall below shall not exceed 120 pounds per square inch, or about 8½ tons per square foot for common brickwork; or 150 pounds, or about 10¾ tons per square foot for common rubble with flat beds.

It is also a good idea to place a flat stone *above* the end of a wooden girder, so that the wall will not rest on the wood, which is quite sure to shrink and possibly affect the wall.

4. TREATMENT OF CUT-STONEWORK IN THE WALL.

305. LAYING OUT ASHLAR.—After the kind and size of ashlar to be used has been determined upon, the draughtsman should show each piece of ashlar on the elevation drawings if coursed-ashlar with plumb bond is to be used, and stones of particular lengths desired. If there are piers on the outside of the building a section drawing should be made showing how the stones in the piers are to be bonded with the rest of the wall.

In all public buildings and most office and business blocks it is generally better to show *every* stone on the plans unless broken-ashlar is to be used, in which case the labor would be wasted. As a rule,

in ordinary stone dwellings, and in fact in most stone buildings, either broken-ashlar or coursed-ashlar of irregular lengths is used, and in either case it is not necessary to indicate the ashlar on the elevation drawings, except to show the heights of the courses, if coursed-ashlar is used. When broken-ashlar is used only the quoins and jambs and a small piece of ashlar indicating the kind of work desired need be shown, as it is almost impossible for masons to carefully follow a drawing showing broken-ashlar.

306. THICKNESS OF ASHLAR.—Broken-ashlar and coursed-ashlar not exceeding 12 inches in height generally varies from 4 to 8 inches in thickness, and averages 6 inches. The different courses should vary in thickness, as shown in Fig. 159, and it is better to have one course 4 inches and the next 8 inches than to have all 6 inches thick. No ashlar, however, even if of marble, should be less than 4 inches in thickness. Ashlar laid in alternating high and low courses, such as 6 inches and 14 or 20 inches, should be cut so that the low courses will be at least 8 inches thick and the high courses 4 inches thick; and each stone in the high thin courses, when 18 inches or more in height, should have at least one iron anchor extending through the wall.

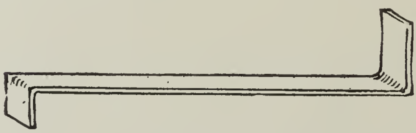


Fig. 155.—Usual Form of Anchor for Thin Ashlar Facing.

Fig. 155 shows the form of anchor generally used. The high courses, when of sandstone or limestone, are generally sawed to a uniform thickness.

307. JOINTS IN CUT-STONEWORK.—It is important that

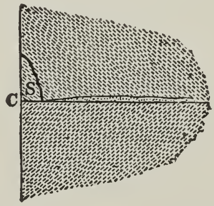


Fig. 156.—Bed-joint in Stonework Worked Hollow.

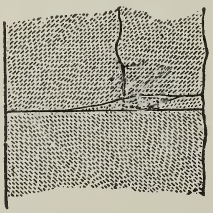


Fig. 157.—Back of Bed-joint in Stonework Slack or Hollow.

the exposed surfaces of each stone should be "out of winde"; that is, true planes and square to the bed-joints and end joints.

The bed-joints should be full and square to the face and not worked hollow, as in Fig. 156, as with hollow joints the least settle-

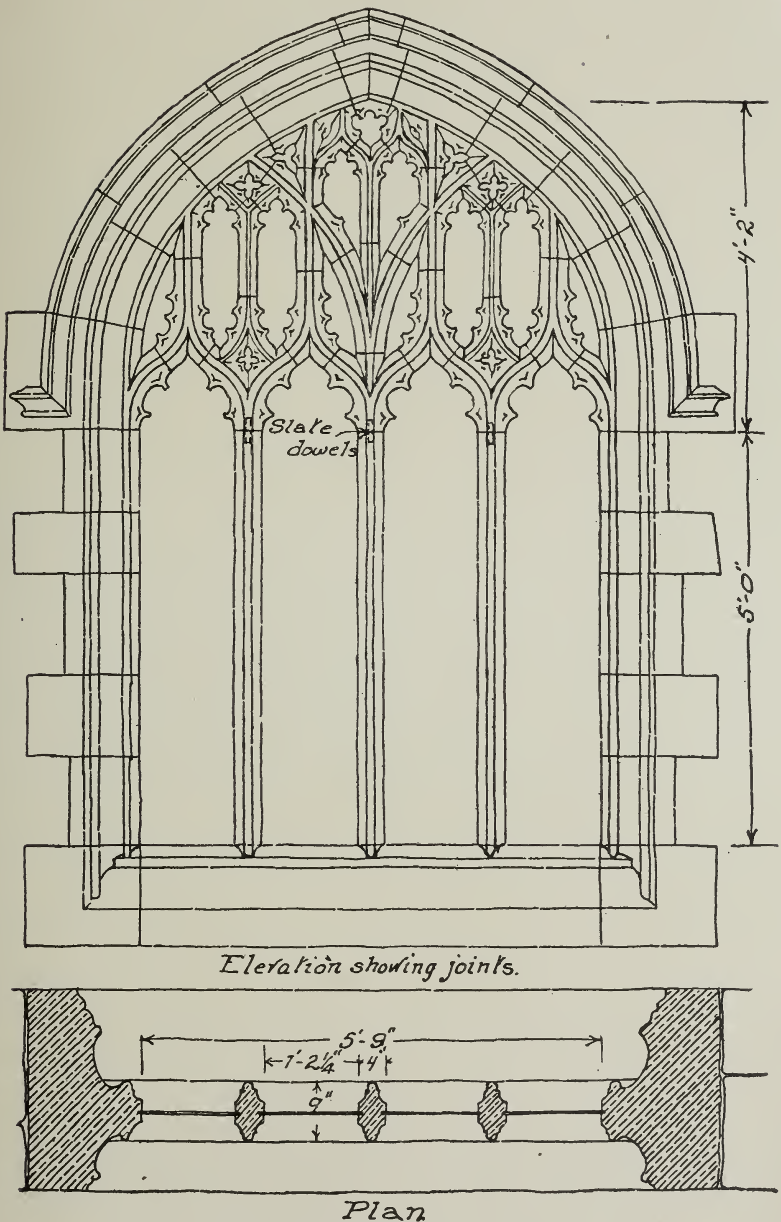


Fig. 158.—Joints in Stone Tracery.

ment in the mortar will throw the whole pressure onto the edge of the stone as shown at *C*, and cause "spalls" or small pieces to splinter off, ruining the appearance of the building, and suggesting unsafe construction. Stone-cutters are very apt to work the joints hollow and the back of the joints slack, as in Fig. 157, as such joints require much less labor than evenly dressed joints; and, unless carefully looked after, they will cut the stones slack in nine cases out of ten. If the back of a joint is left slack and underpinned, as in Fig. 157, the stone is then supported at the front and back only, and is liable to break in the middle, as shown. Of course, in a wall not exceeding 20 feet in height, the danger arising from imperfect joints is not as great as in a wall of six or more stories. The higher the wall the more carefully should the joints be cut. It is also desirable that the joints should not be convex.

For very heavy masonry, as in the basement or first story of tall buildings, it is desirable to use rusticated joints (see Fig. 123), as with such joints the face is less apt to spall.

The thickness of ashlar joints varies from $\frac{3}{16}$ to ½ of an inch. A ¼-inch joint, when pointed, makes very good-looking work. A ½-inch joint is too wide for anything but rock-faced ashlar, and nothing over a ¼-inch joint should be used for heavy work.

308. JOINTS. GENERAL PRINCIPLES. JOINTS IN TRACERY.—The following general principles should be observed in arranging the joints of masonry and cut-stonework:

(1) All bed-joints should be arranged at right-angles to the pressure coming upon them.

(2) All joints should be arranged in such manner that all members, such as sills, shall be free from any cross or flexural stress.

(3) All joints should be arranged in such manner that there are no acute angles on either one of the pieces of stone coming together.

Principle (1) applies to all kinds of masonry, and takes account of the tendency of one stone to slide upon the other.

Principle (2) applies chiefly to stone window and door sills. In stonework, where the sills must be set as the work proceeds, their cracking or breaking may be prevented by making a vertical joint in the line of the face of the reveal, as shown in the elevation of the Gothic window in Fig. 158. When heavy stone mullions transmit considerable weight to the sills, the same precautions must be taken with the latter; while if the mullions are light, and cause no

material pressure, continuous sills may be employed, and no joint is necessary under the mullions. It is better, in all cases, to build the stone tracery work in position, especially if very light, after the building is erected and all settlement has taken place. This prevents any weights being transmitted down through mullions and other portions of the light tracery.

Principle (3) applies especially to the tracery joints, and in general to exposed joints in any other work. Acute angles in cut-stone weather badly, and in stone tracery in which several members intersect, the stones must be cut so as to contain the entire intersection and also a short length of each intersecting member, as shown in Fig. 158. The joints in the different members abutting should always be cut at right-angles to their directions. By this means acute angles are prevented, as they would not be in case the joints were made along the line of either section of the moldings, and a much better finish is insured.

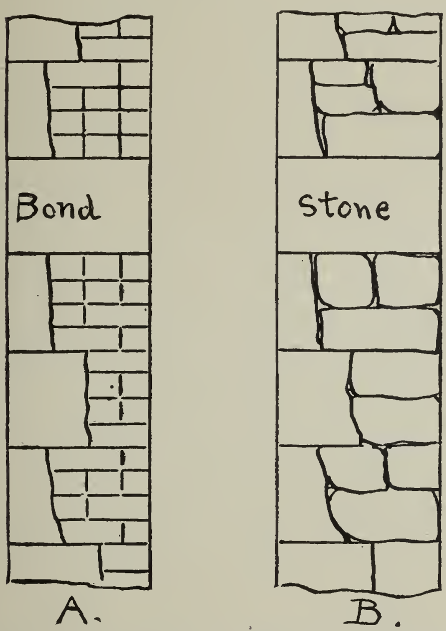


Fig. 159.—Bonding and Backing of Stonework. A. Brick Backing. B. Stone Backing.

Joints should never be made in cut-stonework, in tracery, in string-courses nor in other moldings at any miter line.

Neat and lasting intersections of moldings cannot be cut or carved when mortar joints are made along these lines of intersection.

309. BACKING OF CUT-STONEWORK.—Both stone and brick are used for the backing of ashlar. Brick is used more largely than stone for this purpose, because in most cases it is the cheaper, and because in dry climates plaster can be applied to it directly, whereas, stone backing generally has to be plugged and stripped for lathing. If brick is used for backing, the joints should be made as thin as possible, and it is desirable to use some cement in the mortar to prevent shrinkage in them. The backing, if of brick, should never

be less than 8 inches in thickness. If a hard laminated stone, with perfectly flat and parallel beds can be obtained for backing, a stronger construction will result than if brick is used; but irregular rubble blocks are not suitable for any walls but dwelling-house walls, unless such walls are made one-fourth thicker than they would be with brick backing. The backing, whether of brick or stone, should be carried up at the same time the ashlar is laid, and, if of stone, it should be built in courses of the same height as the ashlar courses, as shown in *B*, Fig. 159.

310. BONDING OF CUT-STONEWORK.—Ashlar not exceeding 12 inches in height is usually sufficiently bonded to the backing by making the stones of different thickness, as in Fig. 159, and by using one through stone to every 10 square feet of wall.

Where the ashlar is only from 2 to 4 inches thick, as is generally the case with marble, and often the case with sandstones, each piece should be tied to the backing by an iron clamp, about 1/8 of an inch thick and 1 or 1 1/4 inches wide, with the ends turned at right-angles, as shown in Fig. 155. The anchors should be made of just the right length for the longer end to turn up close against the inside of the wall. Every stone should have one clamp, and if a stone is over 3 feet long two clamps should be used for it. There should be belt-courses, also, about every 6 feet, extending 8 inches or more into the walls, to add support to the ashlar.

The effective thickness of a wall faced with thin ashlar is the thickness of the backing only. When iron clamps are used for tying the ashlar they should be either galvanized or dipped into hot tar to prevent their destruction by rust.

311. SETTING CUT-STONEWORK.—All stones should be set in a full bed of mortar, and any stone too large to be easily lifted by one man should be set with a derrick.

In some localities slips of wood of the thickness desired for the joints are prepared and laid on the top of the stone below; so that when a stone of a course above is set the mortar squeezes out until the stone rests on these slips. After the mortar has set or hardened the slips are withdrawn. The bed of mortar should always be kept back an inch or more from the edge of the stone. This will prevent the stone from bearing on its outer edge, and save raking out the mortar preparatory to pointing. In damp places stonework should be set in cement, or in lime-and-cement mortar; in dry places it may be set in lime mortar.

Most granular limestones and marbles, and some sandstones, are stained by either Portland or natural cement, and when using any of these stones for the first time the architect should ascertain their liability to be stained. The mortar for bedding the stone can always be kept from its face by exercising a little care, and the joints can be afterward pointed with some material that does not stain. Stonemasons are often very careless in setting stonework, and do not bed the stones evenly, so that when a considerable weight comes upon them they crack.

Marble and limestone are sometimes set in a cement made of lime, plaster of Paris and marble dust, and called Lafarge cement. When such cement is used for setting the cut-stonework, and other cements for the backing, the back of the cut-stone should be plastered with the former cement. Window and door sills should *be bedded at their ends only* with no mortar under the middle part, as otherwise any settlement of the walls will break them.

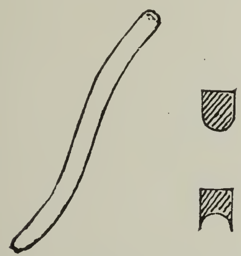


Fig. 160.—Jointer for Stonework Joint.

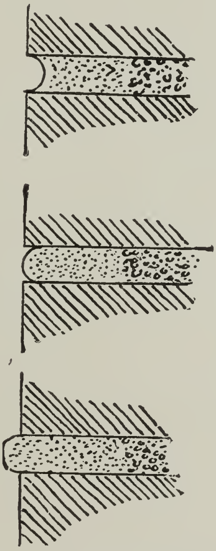


Fig. 161.—Pointed Joints in Stonework.

312. PROTECTING CUT-STONEWORK.—The carpenter's specifications should contain a clause providing for the boxing of all moldings, sills and ornamental work with rough pine to prevent the stone from being damaged during the construction of the building. Hemlock stains the stonework, and should therefore never be used for this purpose.

313. POINTING CUT-STONEWORK.—As the mortar in the exposed edges of the joints is very apt to be dislodged by the expansion and contraction of the masonry and the effects of the weather, it is customary, after the masonry is laid, to refill the

joints to a depth of half an inch or more with mortar prepared especially for this purpose. This operation is called "pointing."

Pointing is generally done as soon as the outside of the building is completed, unless it should be too late in the season, when it should be delayed until spring. Under no circumstances should it be done in freezing weather, and it is better to postpone it in extremely hot weather, as the mortar dries too quickly.

Portland cement mixed with not more than an equal volume of fine sand and such coloring matter as may be required, with just enough water to give the compound a mealy consistency, makes the most durable mortar for pointing. If the stone employed is stained by a cement, either Lafarge cement should be used, or else a putty made of lime, plaster of Paris and white lead.

Before doing the pointing the joints should be raked out to a depth of about an inch, brushed clean and well moistened.

The mortar is applied with a small trowel made for this purpose and is then squeezed in and rubbed smooth with a tool called a "jointer" (Fig. 160). Jointers are made with both hollow and concave edges, so as to give a raised or concave joint, as shown in Fig. 161. The concave joint is the most durable, although the raised joint makes perhaps the handsomest work.

314. CLEANING DOWN CUT-STONEWORK.—This consists in washing and scrubbing the stonework with muriatic acid and water. Wire brushes are generally used for marble work and sometimes for sandstone, but stiff bristle brushes usually answer the purpose just as well. The stones should be scrubbed until all mortar stains and dirt are entirely removed. The cleaning down is done in connection with the pointing.

For cleaning an old front, the sand-blast, using either steam or compressed air, does the work most effectively, as it removes from 1-64 to 1-32 of an inch from the surface of the stone, making it look like new. Even carving can be successfully treated in this way.

315. SLIP JOINTS IN WALLS.—Where two walls differing considerably in height come together, as, for instance, where the front or side wall of a church joins its tower, these two walls should not be bonded together, but the low wall should be "housed" into the other, so as to form a continuous vertical joint from bottom to top, as shown in Fig. 162.

Such a joint is called a "slip joint." All masonwork built with lime mortar will settle somewhat, owing to the slight compression in the joints, and this settlement is sometimes sufficient to cause a crack where a high and low wall are bonded together. In such cases there is a chance also for uneven settlement in the foundations, even when carefully proportioned. With a slip joint a moderate settlement may take place without showing on the outside.

5. STRENGTH OF CUT-STONEWORK.

316. STRENGTH OF STONE PIERS, COLUMNS AND LINTELS.—Practically the only cases in which the strength of stonework need be considered by the architect, other than those having to do with the proper type of construction, are those involving: *a*, the strength of piers; *b*, the strength of columns; *c*, the strength of lintels.

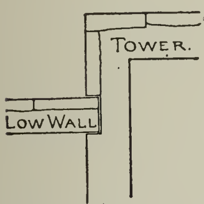


Fig. 162. Slip Joint in Stone Walls.

a. Strength of Stone Piers.—There is a great variation in the strength of stone, even when taken from the same quarry. The strength of walls and piers is also affected by the kind and quality of the mortar used, by the way the work is built and bonded, and it also depends upon whether the stone is laid dry or wet. The values which are usually given, therefore, for strength are values which will be safe for the different kinds of masonry built in the usual manner.

The larger cities have building laws which specify the greatest loads allowed per square foot on stone piers and other kinds of masonry.

A factor of safety of at least 10 should be allowed for stone piers, when the safe resistance to crushing is estimated from tests on the ultimate strength of work of the same character.

Some building ordinances fix the maximum stress for dimension-stone piers at one-thirtieth of the ultimate strength of the stone when the beds are dressed to a uniform bearing over their entire surface, and at one-fiftieth of the ultimate strength when the beds are not dressed. They also require all stones to be bedded in Portland cement mortar when the compressive stress exceeds one-seventieth of the ultimate strength.

The following table gives the safe working loads for stone walls or piers:

TABLE XXIV.

SAFE WORKING LOADS FOR STONE WALLS OR PIERS.

Rubble walls, irregular stones	3 tons per square foot.
Rubble walls, coursed, soft stone	2½ tons per square foot.
Rubble walls, coursed, hard stone	5 to 16 tons per square foot.
Dimension stone, squared, in cement:	
Sandstone and limestone	10 to 20 tons per square foot.
Granite	20 to 40 tons per square foot.
Dressed stone, with ⅜-inch dressed joints in cement:	
Granite	60 tons per square foot.
Marble or limestone, best	40 tons per square foot.
Sandstone	30 tons per square foot.

The height of these piers should not exceed eight times the least dimension in plan.

Ashlar should be at least as thick as it is high and it should be well bonded.

When piers are constructed of strong stone in courses, one stone to each course, and all bedded even and true, they will support very heavy loads. When the height of such pier is greater than eight times the least dimension, there should be a reduction of the safe load, and in any case the height should not exceed ten times the least dimension.

The stones should be laid in 1 to 2 Portland cement mortar, which should be kept back 1 inch from the faces of the pier, and the thickness of the joints should not exceed ⅜ of an inch.*

b. Strength of Stone Columns.—A stone column, free from defects, carefully bedded and not exceeding ten diameters in height, should *safely* carry a load equal to one-fifteenth of the breaking load of stone of the same kind and quality. Any column loaded with over fifteen tons to the square foot should be bedded in Portland cement mortar, of not more than 1 to 1 proportions, and the mortar should be kept back 1 inch from the face of the column until after the work is completed, when the joints may be pointed as in ashlar. As it is difficult to make a mortar joint which will stand more than forty tons to the square foot, that pressure should be the limit of load for a stone column, no matter how strong the stone is, unless extra precautions are taken with such joints. The following values may be used for the safe loads of columns built

* For additional data, records of tests, etc., on "The Working Strength of Masonry," "Stone Piers," "Crushing Resistances of Various Building Stones," etc., see Chapter V of the "Architect's and Builder's Pocket-Book," by F. E. Kidder.

of the different stones specified, the shaft of each column being in one piece:

COLUMNS. ONE PIECE.

Longmeadow (Mass.) red sandstone, best....	35	tons per	square foot.
Potsdam red sandstone....................	40	"	"
Manitou (Colo.) red sandstone, best....25 to	30	"	"
Ohio sandstone...........................	25	"	"
Fond du Lac (Wis.) sandstone.............	25	"	"
Limestone, Glens Falls, N. Y.............	35	"	"
Limestone, Indiana.................25 to	35	"	"
Limestone, strongest varieties...........	40	"	"
Marble, Lee, Mass........................	40	"	"
Marble, Rutland, Vt................30 to	35	"	"
Granite, any, of good quality............	40	"	"

If a column is built up of several pieces the joints should not exceed $\frac{3}{16}$ of an inch in thickness, and the bed surfaces should be perfectly true and square to the axis of the column.

*c. Strength of Stone Lintels.**—A lintel is nothing more than of stone beam, and the same formulas apply to stone and to wood, with the exception of the quantity representing the strength or "modulus of rupture" of the material. The following formulas give the strength of lintels under symmetrically distributed and centrally concentrated loads, the only cases likely to occur in practice:

$$\text{Distributed breaking load} = \frac{2 \times \text{breadth} \times \text{square of depth}}{\text{span in feet}} \times C.$$

Concentrated center breaking load=one-half the distributed load.

The breadth and depth should be taken in inches and the breaking load in pounds. C is one-eighteenth of the average modulus of rupture, and may be taken as follows:

Granite, 100; marble, 120; limestone, 83; sandstone, 70; slate, 300; bluestone flagging, 150.

These formulas give the *breaking strength* of the lintel. If the load on the lintel consists of masonry only, and is not subject to shocks or impacts of any kind, the safe load may be taken at *one-sixth* of the breaking load. If there are any unfavorable circumstances the safe load should not exceed *one-tenth* of the breaking load.

Nearly all laminated stones are stronger, as beams, when set on

* For a discussion of the "General Principles of the Strength of Beams," "Modulus of Rupture" or "Flexural Fiber Strength," "Formulas for the Strength of Beams," "Coefficients for Beams," etc., see Chapters XV and XVI of the "Architect's and Builder's Pocket-Book," by F. E. Kidder.

edge; and where the full strength of a stone is required, and where it is known to weather well, it may with advantage be set in this way and protected from the weather by placing a molded course above, set on its natural bed.

Floor beams, and any construction carrying a live or moving load, should never be supported on stone lintels. These formulas apply to slabs as well as to lintels, although if a slab has a bearing on all four sides its strength is considerably decreased.

Example I.—What is the safe distributed load for a granite lintel over a 6-feet opening, 20 inches in height and 8 inches in thickness?

Solution.—Breaking load $= \dfrac{2 \times 8 \times 20^2}{6} \times 100 = 106{,}666\tfrac{2}{3}$ lbs.

One-sixth of this gives 17,778 pounds for the safe distributed load.

Example II.—What is the safe distributed load for a bluestone flag of 4 feet clear span, 4 feet in width and 4 inches in thickness?

Solution.—Breaking load $= \dfrac{2 \times 48 \times 4^2 \times 150}{4} = 57{,}600$ pounds.

As the load on the flagstone would very probably be a live or moving load, the safe load should be only one-tenth of the breaking load, or 5,760 pounds.

6. MEASUREMENT AND COST OF CUT-STONEWORK.

317. UNITS OF MEASUREMENT.—Rough stone from the quarry is usually sold under two classifications, *rubble-stone* and *dimension-stone.* Rubble includes the pieces of irregular size most easily obtained from the quarry, and suitable for cutting into ashlar 12 inches or less in height and about 2 feet long. Stone ordered of a certain size, or to square over 24 inches each way, and of a particular thickness, is called "dimension-stone." The price of the latter varies from two to four times the price of rubble.

Rubble is generally sold by the ton or carload. *Footings* and *flagging* are usually sold by the square foot; dimension-stone by the cubic foot. In Boston granite blocks for foundations are usually sold by the ton.

In estimating on the cost of stonework *put into the building,* the custom varies with different localities, and even among contractors in the same city.

Dimension-stone footings (that is, square stones 2 feet or more in width) are usually measured by the square foot. If built of large rubble or irregular stones the footings are measured in with the wall, allowance being made for the projections of the footings.

Rubble-work is almost universally measured by the perch of 16½ cubic feet. The author has been unable to find any locality where the legal perch of 24¾ cubic feet is used by stone-masons. In Philadelphia, St. Louis and some portions of Illinois 22 cubic feet are called a perch.

It is customary to measure railroad work by the cubic yard, or 27 cubic feet.

If work is let by the perch, the number of cubic feet that are to constitute a perch should be distinctly stated in the contract, as the custom of the place would probably prevail in case of a dispute. It should also be stated whether or not openings are to be deducted, because, as a rule, rubble walls are figured solid, unless an opening exceeds 70 square feet in superficial area.

Occasionally *rubble* is measured by the cord of 128 cubic feet.

Stone backing is generally figured the same as rubble.

Ashlar is almost invariably measured by the square-foot face, the price varying with the kind of work and size of stones. Openings are generally deducted, but the widths of jambs are usually measured in with the face work. This custom varies, however, with different localities and kinds of work. In common rock-faced ashlar the wall is often figured solid, unless the openings are of unusual size.

Flagging and slabs of all kinds are always figured by the square foot. *Curbing, moldings, belt-courses* and *cornices* are usually figured by the lineal foot, and irregular-shaped pieces by the cubic foot. All *carving* is figured by the piece. Some contractors figure all kinds of *trimmings* by the cubic foot, varying the price according to the amount of labor involved. Others figure the number of cubic feet in all the stone, to get the value of the rough stone, and then figure the labor separately, so much per lineal foot for moldings, so much for the columns, etc., giving a separate figure for carving. This is the most accurate method, and is usually employed by contractors for granite work. Of course, considerable experience is necessary in order to know how much to allow for labor, while the value of the stone itself can be very easily computed.

318. THE COST OF STONEWORK.—The prices of different kinds of stonework vary according to the value of the stone, the

cost of quarrying, the transportation, the demand, the prevailing wages, the sizes of the stones, the amount of cutting, carving and dressing, etc.

It is impossible to give data for estimating a cost that will not vary between wide limits, and any figures given would serve only as approximations or guides in forming rough estimates.*

7. SUPERINTENDENCE OF CUT-STONEWORK.

319. SUPERINTENDENCE IN GENERAL.—As with all other building operations, the superintendent needs to be very watchful in inspecting the cut-stonework and its setting to prevent defects and imperfect work from being imposed upon him. When a stone is once built into a wall it can be removed only at considerable expense and after delay and much vexation; and it is therefore important that all defects be discovered before it is set. The superintendent must be well posted on the various ways in which defects are covered up, so that he will discover them, if they exist, and he must have sufficient firmness to demand that all unsound or defective stones shall be replaced by sound ones, and that the work shall be done in the manner directed by the architect.

Defects.—The following are the defects most likely to occur in cut-stonework:

Good granites are liable to contain local defects, such as seams, black or white lumps called "knots," and also brown stains known as sap. Any of these defects should be sufficient cause to reject the stone. Seams may be detected by striking the stones with a hammer, and those which do not ring clearly should be rejected.

In sandstones the two most common defects are "sand holes," which are small holes filled with sand, without any cementing material to prevent the sand from washing out, and uneven color. Stones from the same quarry often vary considerably in color, and the superintendent must see that the color of the stone is uniform throughout.

Patching.—Often in cutting a stone a small piece is broken off from a large stone, and the contractor, rather than throw the stone away, either sticks the piece on again or cuts out the fractured part and fits in a new piece. The pieces are glued on with melted shellac

* For "Data for Estimating Cost of Stonework," of all kinds, with average prices and quotations for labor and materials, see discussion under this heading in Part III of the "Architect's and Builder's Pocket-Book," by F. E. Kidder.

and then rubbed with stone dust until they cannot be detected by a casual glance, and it is necessary for the superintendent to look very closely at the stones in order to be sure that they are not patched in this way.

At first these patches are hardly noticeable and do no harm, but when the stone gets wet the patch becomes conspicuous, and in time the shellac in the joint is washed away and the patch drops off.

When the damaged stone is large, and cannot be replaced except at great expense and considerable delay, the superintendent might consent to have it patched, but he should see that it is done correctly, and, where possible, a square hole cut in the stone and a corresponding piece tightly fitted in, and then cut to fit the stone or molding. If it is on the corner of a stone, the piece can generally be dovetailed, so that it will stay in place without the aid of shellac. If any patched stones are put into the building the superintendent should know of it beforehand, and, as a rule, it is wise to consult the owner of the building about it before the stone is set.

Poor Workmanship.—In the cutting of the stone the most common fault to be found is poor workmanship or too coarse a surface. Naturally, the finer a surface is tooled or crandalled the greater the expense, and hence contractors generally finish the stone with as coarse a finish as they think the superintendent will pass. Very often, also, sufficient care is not taken in matching the ends of molded belt-courses, cornices, etc. The superintendent should insist on having all the pieces cut exactly to the same pattern, and all edges true and free from nicks.

Scant Stone Window Sills.—It is not unusual to find some window sills that are not of sufficient width to be well covered by the wood sills. The back of the stone sills should extend at least 1½ inches back beyond the face of the wood sill, and the back of the wash should be cut to a straight line, without any holes or scant surfaces.

Ashlar Work.—The ashlar, especially when rock-faced, is apt to be too thin in places, and to have very poor bed-joints. The superintendent should insist on having the bed-joints, top and bottom, at least 3 inches wide at the thinnest part, and on having them cut square to the face of the work. He should also examine the stones to see if they have been cut so as to lie on their natural beds. The proper bonding and anchoring of the ashlar and trimmings should also receive careful attention.

Stone Gable Copings.—The anchoring of gable copings should be

especially looked after, as not infrequently such copings slide out of place and fall to the ground from neglect in this particular. One would naturally suppose that the builder himself would see that his work is done securely, if not handsomely; but it seems to be a general fault among builders to trust a good deal to luck, and to use as few precautions as possible to insure it. In these days, when there is a tendency to do everything with a rush, there are also many builders who are ignorant of the best methods of doing work, or who consider them unnecessary and not "practical."

Anchoring Stone Finials.—When finials or similar stones are cut into two pieces, they should be secured together by iron dowels set in almost neat Portland cement. The superintendent should constantly bear in mind the fact that stonework cannot be too securely anchored and bonded.

Omitting Mortar from Face Joints of Cut-stone.—The superintendent should caution the foreman, when setting arches, columns, etc., to keep the mortar about ¾ of an inch back from the face of the stones. Molded arches, particularly, need to be set with great care, for if the mortar comes out to the face the joints may be a little full at the edges and cause the moldings to "sliver" or "spall" at those points. It is not uncommon to see arch stones and columns cracked because of the neglect of this precaution.

Pointing of Cut-stonework.—When the pointing is being done the superintendent must carefully watch the operation of raking out the joints to receive it. The old mortar should be raked out to a depth of at least ¾ of an inch. If the work is not watched, however, it may be found after a year or two that the raking out of the joints was only partially done, if not altogether neglected, and that the pointing mortar was struck only on to the face of the joints.

There will naturally be many other matters in connection with the stonework requiring careful supervision to secure a good and durable job, but careful attention to those above noted will lead to a pretty thorough inspection of the whole work.

Chapter VII.

Bricks and Brickwork.

1. BRICKS—MANUFACTURE, KINDS AND USE.

320. GENERAL NOTES AND DESCRIPTION.—Bricks are more extensively used in the construction of buildings than any other material except wood, and with the rapidly increasing scarcity of timber it is probable that before long bricks, terra-cotta and concrete will largely take the place of wood in many kinds of construction. At the present time brick, terra-cotta and concrete architecture is decidedly in the ascendency, and a great deal of capital is invested in the manufacture of bricks of all kinds, shapes and colors.

As far as durability is concerned, good bricks are to be preferred to stone, as they are practically indestructible, either from the action of the weather, from the acids of the atmosphere or from fire; they may be had in almost any desirable shape, size or color, and are more easily handled and built into a wall than stone. Brickwork is also much cheaper than cut-stonework, and in most localities is less expensive than common rubble. Unfortunately, however, all bricks cannot be classed under the above heading, as there are many that are soft and porous, and far from durable when exposed to dampness. Except in very dry soils brickwork is not as suitable as stonework for foundations, nor can it be used for piers and columns that support very heavy loads.

As there are many different kinds and qualities of bricks, as well as good and bad methods of using them, the architect must know something about their manufacture and their characteristics; and also about the best methods of using them in order to properly prepare his designs and specifications and to superintend the construction.

321. COMPOSITION OF BRICKS.—Ordinary building bricks are made of a mixture of clay and sand (to which coal and other foreign substances are sometimes added), which is subjected to various processes, differing according to the nature of the materials,

the methods of manufacture and the character of the finished products.

After being properly prepared the clay is put into molds of the desired shape; then taken out, dried and burned.

The Clay.—The quality of a brick depends principally upon the kind of clay used. The material generally employed for making common bricks consists of a sandy clay, or silicate of alumina, usually containing small quantities of lime magnesia and iron oxide. If the clay consists almost entirely of alumina it will be very plastic; but it will shrink and crack in drying, and warp and become very hard under the influence of heat.

Silica, when added to pure clay in the form of sand, prevents cracking, shrinking and warping, and allows a partial vitrification of the materials. The larger the proportion of sand present the more shapely and the more uniform in texture will be the bricks. An excess of sand, however, renders the bricks too brittle and diminishes the cohesion. Twenty-five per cent of silica is said to be a good proportion.

The presence of *oxide of iron* in the clay renders the silica and alumina fusible and adds greatly to the hardness and strength of the bricks. Iron has a great influence also upon the color of the bricks (see Article 334), the red color being due to its presence. A clay which burns to a red color will make stronger bricks, as a rule, than one whose natural color when burned is white or yellow.

Lime has a twofold effect upon the clay containing it. It diminishes the contraction of the raw bricks in drying, and it acts as a flux in burning, causing the grains of silica to melt, and thus bind the particles of the bricks together. An excess of lime causes the bricks to melt and lose their shape. Again, whatever lime is present must be in a very divided state. Lumps of limestone are fatal in a clay used for brickmaking. When a brick containing a lump of limestone is burned the carbonic acid is driven off, and the lump is formed into quicklime which is liable to slake as soon as the brick is wet or exposed to the weather. Pieces of quicklime not larger than pin-heads have been known to detach portions of a brick and to split it to pieces. The presence of lime may be detected by treating the clay with a little dilute sulphuric acid. If there is lime present an effervescence will take place.

For the best qualities of pressed bricks the clay is carefully selected for both chemical composition and color; and very often two or three qualities of clay from different sources are mixed together to obtain the desired composition.

Clays of especially fine quality are often mixed and shipped, like other raw materials, to distant parts of the country.

322. MANUFACTURE. (1) HAND-MADE BRICKS.—Most of the common bricks used in this country, especially in the smaller towns and cities, are still made by hand. The process consists of throwing the clay into a circular pit, where it is mixed with water and tempered with a tempering wheel worked by horse power until it becomes soft and plastic, and then taking it out and pressing it into molds by hand. Unless the clay contains sufficient sand already, additional sand is added to it as it is put into the pit, and coal dust or sawdust is often added to assist the burning. In some localities screened cinders are mixed with the clay.

In molding bricks by hand the molds are dipped in either water or fine sand to prevent the bricks from adhering to the molds. If the molds are dipped in water the process is called "slop-molding," and if in sand the bricks are called "sand-struck." The latter method gives cleaner and sharper bricks than those produced by "slop-molding."

After being shaped in the mold the bricks are laid in the sun, or in a dry-house, to dry for three or four days, after which they are stacked in kilns and then fired.

When the green bricks are dried in the open air they are occasionally caught in a shower, which gives them a pitted effect, that is generally considered undesirable. Unless the edges are much rounded, however, this does not affect the strength of the bricks, and they may be used in the interior of walls.

323. MANUFACTURE. (2) MACHINE-MADE BRICKS.—Where bricks are made on a large scale the work is now done almost entirely by machinery, commencing with the mining of the clay by steam-shovels and ending by the burning in patent kilns.

Machines in great variety are now made for preparing the clay and for making the raw bricks. They differ more or less widely in construction and principle, but may be divided into three classes, according to the methods of manufacture for which they are adapted.

There are practically three processes employed in making bricks, viz.: *a.* The *soft-mud* process; *b.* The *stiff-mud* process, and *c.* The *dry-clay* process. The machines are also classed under these same headings.

The general processes are as follows:

a. The Soft-mud Process.—This is essentially the same process as that employed when the bricks are made by hand. When machinery is used the various steps are about as follows: As the clay is brought from the bank it is thrown into a pit (about 6 feet deep and 8 by 12 feet in area) lined with planks. Water is then turned into this pit and the clay allowed to soak for twenty-four hours. Three pits are generally provided, so that the clay in one may be soaking while the second is being emptied and the third being filled. If coal-dust is to be mixed with the clay it is thrown into the pit in the proper proportions. After soaking twenty-four hours in the pit the clay is thrown out on an endless chain, which carries it along to the machinery, into which it falls. The upper part of a soft-clay machine contains a revolving shaft, to which arms are affixed. These arms break up and thoroughly work the soft clay, which falls to the bottom of the machine, where revolving blades force it forward; and a plunger working up and down then forces it into a mold placed under an opening. The filled mold is then drawn or forced out on a shelf or table and another mold placed under the opening. There are several types of machines, but they all work on about this plan. Sometimes the clay is worked in a pug-mill before being thrown into the machine.

After being drawn from the machines the filled molds are emptied by hand and the bricks taken to the dry-sheds. For drying soft-mud bricks the "pallet" system is generally employed. The "pallets" are thin boards about 12 by 24 inches in size. The bricks are placed on these, which are then put upon racks, arranged so that the air will have free circulation. The stacks should always be protected by a low roof covering.

b. The Stiff-mud Process.—The essential difference between this process and the foregoing is that in the stiff-mud process the clay is first ground, or disintegrated, and only enough water added to make a stiff mud. This mud, after being pugged, is forced

through a die in a continuous stream, whose cross-section is the size of a brick, and the bricks are then cut off.

The process varies more or less in different yards and with different clays; but when most thoroughly carried out the various steps in their order are as follows: First, the mining of the clay; secondly, the breaking up of the lumps (generally in a pug-mill); thirdly, the grinding of the clay, either in a separate pug-mill or in the machine, and fourthly, the passing of the clay through the machine and the cutting off of the bricks.

There are two primary types of stiff-mud brick-machines, viz.: The auger type and the plunger type. Of these the auger machines are the more numerous and are generally considered the more satisfactory. The auger machine consists of a closed tube of cylindrical or conical shape, in which, on the line of the axis of the tube, a shaft revolves. To this shaft the auger and auger knives are attached. The knives are arranged so as to cut and pug the clay and force it forward into the auger. The function of the auger is to compress and shape the clay and force it through the die. When the clay passes through the die it is compressed as much as is possible in its semi-plastic condition. The opening in the die is made the same size as either the end or the side of a brick, and a continuous bar-shaped stream of clay is constantly forced through it and on to a long table. Various automatic arrangements are provided for cutting up this bar into pieces the size of a brick. If the section of the bar is the same size as the end of a brick, the bricks are called "end-cut"; if the section of the bar is that of the side of a brick, the bricks are called "side-cut." With the end-cut bricks the clay may issue from the machine in one, two, three or even four streams.

From the cut-off table the green bricks pass to the off-bearing belts, from which they are taken to the repressers or driers.

In the plunger brick-machine the clay is forced into a closed box or pressing-chamber, in which a piston or plunger reciprocates and forces the clay through the die. The action of this type of machine must of necessity be intermittent. When the plunger machine is used the clay is generally tempered in a pug-mill before passing to the machine.

c. The Dry-clay Process.—This process is especially adapted to

clays that contain only about 7 per cent of moisture as they come from the banks, the clays being apparently perfectly dry. Wet clays are sometimes dried and then subjected to the same treatment, but the expense of drying materially increases the cost of manufacture.

The various operations generally employed in making bricks by this process may be briefly described as follows:

The first step is the mining of the clay, which may be done either by hand or with steam-shovels, as circumstances may determine. After being mined the clay is generally stored under cover, in order to have a supply always on hand, and also to permit of further drying and disintegrating. Sometimes, however, the clay is taken directly from the bank to the dry-pans.

Probably most of the dry-press bricks are made from two or more grades of clay, mixed in proportions determined by trial as it is thrown into the dry-pans.

From the dump the clay is thrown into a dry-pan, which is a circular machine about 4 feet in diameter and 2 feet deep, with a perforated metal bottom. In this machine, or pan, as it is called, are two wheels, which constantly revolve on a horizontal axis and grind the clay between them and the bottom of the pan, the pan itself revolving at the same time. The clay as it is ground passes through holes in the bottom of the pan and falls to a wide belt, which carries it above an inclined screen, upon which it falls. The portions of the clay that are ground fine enough fall through the screen and on another belt, and the coarser particles roll into the dry-pan, to be again ground and carried to the screen.

The belt which receives the fine clay from the screen carries it to a mixing-pan, a machine contrived to thoroughly mix the particles of the clay. From the mixing-pan the clay falls into the hopper of the pressing machine, and from the hopper it falls into the molds, where it is subjected to great pressure, and compressed to the size of the bricks. The pressed bricks are then pushed out and on to a table. From the table of the machine the bricks are taken by hand, placed on a barrow, or car, and transferred to the kiln.

Different manufacturers vary these operations somewhat, but the processes, and also the machines, used in manufacturing pressed bricks are essentially like the above.

The pressing machines are so constructed that the loose clay is made to evenly fill steel boxes of the widths and lengths of the intended bricks, but much deeper. Into these boxes plungers are forced, which compress the clay until the desired thicknesses are reached, when the plungers stop. If the clay falls more compactly into one box, or mold, than into another, the bricks from the first mold will be the denser, as the plunger falls just so far, no matter how much clay is in the mold.

Molded bricks are made in exactly the same way, the only difference being that the boxes are made to give the desired shape of bricks.

Most of the pressed-brick machines admit a small jet of steam into the clay to slightly moisten it just before it passes into the molds.

Bricks made by this process are very dense and generally show a high resistance to compression; but the general opinion is that the particles do not adhere as well as when the clay is tempered, and that dry-pressed bricks will not prove as enduring as soft-mud bricks, although the former are now more extensively used for face-bricks.

When the term "pressed bricks" is used it should refer to bricks made by the dry process, although many so-called pressed bricks, or face-bricks, are made by re-pressing soft-mud bricks.

324. COMPARISON OF SOFT-MUD AND STIFF-MUD BRICKS.—Soft-mud bricks are made under little or no pressure, and are, therefore, not as dense as the stiff-mud bricks. It is claimed, however, that in the soft-mud bricks the particles adhere more closely, and that when they are properly made and burned they are the most durable of all bricks. Soft-mud bricks, after having lain in a foundation on the shore of a river for fifty-four years, were found in as perfect condition as when laid. Soft-mud bricks are also generally more perfect in shape than stiff-mud bricks and better adapted for painting.

Stiff-mud bricks, owing to the nature of the clay and the details of manufacture, often contain laminations, or planes of separation, which more or less weaken them.

Those made by the plunger machine also sometimes contain voids caused by the air which occasionally passes with the loose clay into the pressure chamber, and being unable to escape, passes out

again with the clay stream which it renders more or less imperfect. The manufacture of stiff-mud bricks, however, is constantly increasing.

In some localities soft-mud bricks are the cheaper; in others the stiff-mud bricks have the advantage. The difference in cost, however, is usually very slight.

The soft-mud bricks take longer to dry, but are more easily burned.

325. RE-PRESSING.—Both soft and stiff-mud bricks are often re-pressed in a separate machine. Re-pressing reshapes the bricks, rounds the corners if required, trues them in outline and makes a considerable improvement in their appearance. Properly formed stiff-mud bricks, however, are not improved in structure by re-pressing.

326. DRYING AND BURNING.—Bricks made by the soft-mud process always have to be dried before being placed in the kiln; those made by the stiff-mud process are generally, although not always, stacked in a dry-house from twelve to twenty-four hours. The drying of the bricks is an important process, and where they are manufactured on a large scale the drying is generally accomplished by artificial means.

After being sufficiently dried they are stacked in *kilns* and burned.

Three types of kilns are used for burning bricks, viz.: *Up-draft, down-draft* and *continuous kilns*.

327. UP-DRAFT KILNS.—These kilns were almost universally used in this country for burning bricks previous to 1870, and are still used more than either of the other types, especially in small yards where the bricks are manufactured by hand.

The old-fashioned up-draft kilns are nothing but the bricks themselves built into piles from 20 to 30 feet wide, from 30 to 40 feet long and from 12 to 15 feet high. The sides and ends of the piles are plastered with mud to keep in the heat, and the tops are generally covered with dirt and sometimes protected with shed roofs.

The bricks are piled so as to form a row of arched openings extending entirely across the kilns, and in these openings the fires are built. The dried bricks are loosely piled above these arches, and as the kilns are burnt, those nearest the fire are so intensely

heated that they become vitrified, while those at the tops of the kilns are but slightly burned, with a gradual graduation of hardness between them. It is from this difference in the burning that the terms "arch-brick," "red brick" and "salmon brick" originated. As the natural tendency of heated air is to rise and to produce a draft, its direction is upward, and hence the name "up-draft" kiln.

The modern up-draft kilns have permanent sides made of from 12 to 16-inch brick walls laid in mortar, and heat is generated in ovens with iron grates built outside of the permanent walls. Only flames and heat enter the kilns through fire passages in the walls connecting the furnaces with the kilns proper. The tops of the kilns, also, are paved with smooth, hard bricks, laid so as to form close covers that can be opened or closed as desired. The bricks are piled in the same way as described above, the arches being left opposite the furnaces. With these improvements the bricks can be much more evenly burned and with a smaller consumption of fuel. The burning of a kiln of bricks requires about a week. After the fires have been burning a sufficient length of time they are permitted to go out, and all the outside openings are tightly closed to keep out the cold air, and thus allow the bricks to cool gradually. It requires much skill and practice to burn a kiln of bricks successfully.

328. DOWN-DRAFT KILNS.—Kilns of this class require permanent walls and tight roofs. The floors must be open and connected by flues with chimneys or stacks. These kilns are more often made circular in plan and in the shape of beehives, although they are also made rectangular in plan. The heat is generated in ovens built outside of the main walls, and the flames and gases enter the kilns through vertical flues, carried to about half the height of the kilns. The heat, therefore, practically enters the kilns at the top and being drawn downward by the draft produced in the chimneys, passes through the piles of bricks and the openings in the floors into the flues beneath, and hence to the chimneys or shafts. It is claimed that all kinds of clay wares can be burned more evenly in drawn-draft kilns. Terra-cotta and pottery are almost always burned in such kilns. For terra-cotta and pottery the beehive-shapes are generally used, several kilns being connected with one stack.

329. CONTINUOUS KILNS.—These derive their name from the fact that the heat is continuous and the kilns kept continuously burning. Continuous kilns are very different, both in construction and working, from the other two types, and the expense of building them is also relatively great. There are various types of continuous kilns, each being protected by letters patent.

The most common type is that of two parallel brick tunnels connected at the ends. The outer walls are sometimes 8 feet thick at the bottom and 4 feet thick at the top. Numerous flues are built in these walls. The coal in continuous kilns is put in at the top. The bricks are piled in the kilns in sections, which are separated by paper partitions, each section being provided with about four openings in the top for putting in the coal. After a kiln is started, one section at a time is kept burning, and the heated gases are drawn through the next section so as to dry the bricks in that section before burning. There are often twenty or more sections in one kiln, and while some sections are burning and some drying, others are being filled and others cooling or being emptied.

Continuous kilns require a powerful draft to make them work successfully, and this draft is generally provided by tall stacks.

The principal advantages claimed for continuous kilns are that they take less fuel to burn the bricks, and that a greater percentage of No. 1 bricks are obtained than with other kilns. The question of the kind of kiln to be used, however, is principally one of economy to the manufacturer, as it makes no particular difference to the architect in what kind of a kiln the bricks are burned.

330. GLAZED AND ENAMELLED BRICKS.—These terms are used to designate bricks that have a glazed surface, the term "enamelled" being applied indiscriminately to all bricks having such a surface.

There is, however, quite a difference between glazed bricks and enamelled bricks. The true enamel is fused into the clay without an intermediate coating, and the enamel is opaque in itself; whereas a glaze is produced by first covering the clay with a "slip" and then with a second coat of transparent glaze resembling glass.

In the manufacture of glazed bricks the unburnt bricks are first coated on the sides which are to be glazed with a thin layer of "slip," which is a composition of ball-clay, kaolin, flint and feldspar. The slip adheres to and covers the clay, and at the same

time receives and holds the glaze. The glaze, which is put on very thin, is composed of materials which fuse at about the temperature required to melt cast-iron, and which leave a transparent body covering the white slip. With glazed bricks it is the slip that gives them their color; and as the slip covers them they may be either red or white. Not all bricks, however, are suitable for glazing.

Enamelled bricks are made from a particular quality of clay, generally containing a considerable proportion of fire-clay. The enamel may be applied either to the unburned bricks or to the bricks after they are burned. The latter method, it is claimed, produces the most perfect bricks.

In burning, the enamel fuses and unites with the body of the brick; but as it does not become transparent, each brick shows its own color.

The manufacture of genuine enamelled bricks is a much more expensive operation than that of glazed bricks, besides involving very difficult processes. For this reason the glazing process is the one generally employed, both in this country and in England.

It is claimed that enamelled bricks are more durable than glazed bricks and that they will not chip or peel so readily. Enamel also shows a purer white.

Enamelled surfaces may be distinguished from those which are simply glazed by chipping off pieces of the bricks. Glazed bricks show the layer of slip between the body and the glaze, while enamelled bricks show no line of demarcation between the body and the enamel.

After the bricks are in the wall none but an expert can distinguish between the two kinds. Probably most of the so-called enamelled bricks that have been used in this country are really glazed.

Each brick is, of course, enamelled or glazed only on one face, or one face and one end. The color is generally white, although light blue and some other colors can be obtained.

Until quite recently most of the glazed bricks used in this country were imported from England, but there are now many factories in this country making them, and they produce a very large percentage of all the glazed bricks now used in the United States.

Enamelled bricks generally differ in size from ordinary bricks.

The sizes of the English bricks are 3 inches by 9 inches by 4½ inches. Part of the American factories adhere to the English sizes, while others make the regular American sizes.

The American glazed bricks are now more nearly perfect than when first put on the market, and appear to be giving satisfaction.

The genuine enamelled bricks are just as good for exterior as for interior use. They will stand the severest climatic changes, and may be used in any climate and in any situation. They are also fire-proof.

Both glazed and enamelled bricks reflect light, acquire no odor, are impervious to moisture and form a finished and highly ornamental surface.

Use.—Glazed and enamelled bricks, on account of the above properties, are very desirable for facing the walls of interior courts, elevator shafts, toilet-rooms, etc., and especially for use in hospitals. They may be used also with good effect in public waiting-rooms, corridors, markets, groceries and butter stores, and wherever clean, light and non-absorbent surfaces and those which will stand drenching with water are required.

331. PAVING BRICKS.—The introduction of brick paving for streets has led to the manufacture of this class of bricks on an extensive scale.

Paving bricks do not strictly come within the province of the architect; but as he may have occasion to use such bricks for paving driveways, etc., it is well for him to know something about them.

Thin paving bricks are also sometimes used for paving flat roofs of office-buildings, apartment-houses, etc.

Paving bricks are commonly made by the stiff-clay process, and the bricks, after being cut from the bar, are generally, although not always, re-pressed to give them a better shape. The clay used for making these bricks is generally shale, almost as hard as rock, although it is sometimes found in a semi-plastic condition. With the shale a certain proportion, often 30 per cent, of fire-clay is generally added.

The principal difference in the manufacture of paving bricks and common building bricks is in the burning. Paving bricks, to stand the frost and wear, must be burned to vitrification, or until the particles of the body have been united in chemical combination by

means of heat. Besides being vitrified, paving bricks are also *annealed*, or toughened, by controlling the heat and permitting the bricks to cool under certain conditions.

Paving bricks, in order to resist the wear and disintegration to which they are exposed in streets or driveways, or even on roofs, must be homogeneous and compact in texture, and must be vitrified and tough. They should be free from loose lumps of uncrushed clay, extensive laminations and fine cracks or checks of more than superficial character or extent; and they should not be so distorted as to lie unevenly in the pavement. They should be free from lime or magnesia in the form of pebbles, and should show no signs of cracking or spalling after remaining in water ninety-six hours. They should have a crushing strength of not less than 8,000 pounds per square inch,* and a modulus of rupture of from 1,800 to 2,500 pounds per square inch.

The best test of vitrification is that of porosity. A common hard-burned brick may be very dense and strong and still absorb from 10 to 15 per cent of water. The same brick when vitrified will absorb much less water.

Engineers, when specifying bricks for pavements, generally limit the absorption to 3 or 4 per cent, the bricks being first dried to 212 degrees Fahr. It is claimed, however, that a brick may be vitrified and still absorb as high as 6 or 8 per cent, owing to its containing considerable air spaces. The density or specific gravity also gives a valuable idea of the degree of vitrification of paving bricks. Great density or high specific gravity usually indicates durability.

For testing the toughness and resistance to wear under the horses' feet, a machine resembling a barrel and called a "rattler" is used. Several bricks together with pieces of scrap iron are put into the rattler, which is then revolved rapidly for a given length of time. The amount that the bricks lose in weight is taken as the test of their durability.

It is claimed by good authorities that the rattler test when properly conducted is the most important test for durability, and that any bricks which will successfully withstand this test will be found satisfactory.

332. FIRE-BRICKS.—Fire-bricks are used in places where a

* H. A. Wheeler, E. M., in the *Clay Worker*, August, 1895.

very high temperature is to be resisted, as in the lining of furnaces, fireplaces and tall chimneys. The ordinary fire-bricks used for the above purposes are made from a mixture of about 50 per cent raw flint clay and 50 per cent plastic clay, the proportion varying with different manufacturers. The bricks are made both by the stiff-mud and dry-press processes, and also by the soft-mud process with hand molding. It is claimed that the last process gives the most perfect bricks.

Fire-bricks, to admit of rapid absorption or loss of heat, should be open-grained or porous, and at the same time free from cracks. They should also be uniform in size, regular in shape, homogeneous in texture and composition, easily cut and infusible.

Fire-bricks are generally larger than the ordinary building bricks.

333. CLASSES OF BUILDING BRICKS.—*Common Bricks.*—This term includes all those bricks which are intended simply for constructional purposes, and with which no especial pains are taken in their manufacture. There are three grades of common bricks, determined by their position in the kiln.

Arch-bricks or hard bricks are those just over the arch, and which, being near the fire, are usually heated to a high temperature and often vitrified. They are very hard, and if not too brittle are the strongest bricks in the kiln. They are often badly warped, so that they can only be used in footings and in the interior of walls and piers.

Red or well-burned bricks should constitute about half the bricks in the ordinary up-draft kiln; and when made of clay containing iron they should be of a bright red color. For general purposes they constitute the best bricks in the kiln.

Salmon or soft bricks are those which form the top of the kiln and are usually underburned. They are too soft for heavy work or for piers, though they may be used for filling in light walls and for lining chimneys.

The strength and hardness of common bricks of all grades vary greatly with the locality in which they are made on account of the difference in the clay. Some of the salmon bricks of New England are fully as hard and strong as the red bricks of other localities, particularly the West. As the color of bricks may be due more to the presence or absence of iron than to the burning, it cannot be used as an absolute guide to their quality.

Stock bricks are hand-made bricks which are intended for face-work, and with which greater care is taken in the manufacture and burning than with common bricks. In the East they are sometimes called *face-bricks.*

The expressions *pressed bricks* or *face-bricks* generally refer to bricks that are made in a dry-press machine, or that have been re-pressed. They are usually very hard and smooth, with sharp angles and corners and true surfaces; and they may be either stronger or weaker than common bricks, according to the character of the clay and the extent to which they are burned. Pressed bricks are not usually burned as hard as are common bricks, and they are, therefore, sometimes not as durable. Pressed bricks cost from two to five times as much as common bricks, and are, therefore, generally used only for the facings of walls.

Molded bricks, arch-bricks and circle bricks are special forms of pressed bricks. A great variety of molded or ornamental bricks are now made, by means of which moldings and cornices may be built entirely of bricks. Most of the companies manufacturing pressed bricks will also make any special shapes of bricks from an architect's designs. Arch-bricks are made in the form of truncated wedges and are used for the facing of brick arches. They can be made for any radius required. Circle bricks are made for facing the walls of circular towers, bays, etc. The radius of the bay should be given when ordering these bricks.

Radial Blocks.—Radial blocks for chimney construction are made in several forms and are designed to fit the curve and radius of the chimney in which they are used, their purpose being to reduce the area and number of mortar joints and increase the bond. Properly designed blocks make much stronger chimneys than can be made with ordinary bricks. See Article 374.

334. COLOR OF BRICKS.—The color of common bricks depends largely upon the composition of the clay and the temperature to which it is raised. Pure clay, free from iron, will burn white, but the color of white bricks is generally due to the presence of lime. Iron in the clay produces a tint which varies from light yellow to orange and red, according to the proportion of iron contained in the clay. A clear bright red is produced by a large proportion of oxide of iron, and a still greater proportion of iron gives a dark blue or purple color. When the bricks are intensely

heated the iron melts and runs through, causing vitrification and giving increased strength. The presence of iron and lime produces a cream or light drab color. Magnesia produces a brown color, and when present with iron makes the bricks yellow.

The color of pressed bricks is, of course, the same as that of common bricks made from the same clay; but pressed bricks are also colored artificially, either by mixing together clays of different chemical composition, or by mixing mineral paints or mortar colors with the clay in the dry-pan. Bricks are also sometimes colored by applying a mineral pigment to their faces before burning. This latter method, however, is not very satisfactory. At the present time the use of colored bricks is very popular, and face-bricks are made in all shades of red, pink, buff, cream and yellow. Some of these colors

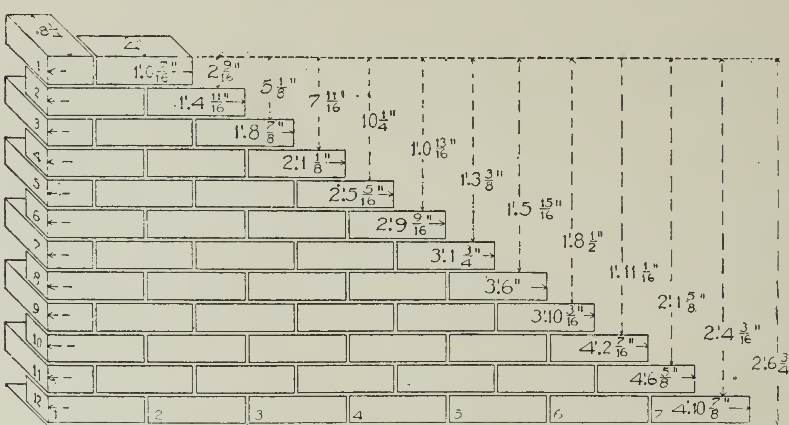


Fig. 163.—Diagram of Coursing for 8¼ by 4 by 2⅜-Inch Bricks, 3/16-Inch Joints.

are very effective when used in an artistic manner, but the use of colored bricks has been much abused, and it requires a fine sense of color to use them effectively, especially where two or more shades are used in the same building.

335. SIZES AND WEIGHTS OF BUILDING BRICKS.—In this country there is no legal standard for the size of bricks, and the dimensions vary with the maker and also with the locality. In the New England States the common bricks average about 7¾ by 3¾ by 2¼ inches. In most of the Western States common bricks measure about 8½ by 4⅛ by 2½ inches, and the thicknesses of the walls measure about 9, 13, 18 and 22 inches for thicknesses of 1, 1½, 2 and 2½ bricks. The sizes of all common bricks vary considerably

in each lot, according to the degree to which the bricks are burnt; the hard bricks being from ⅛ to $\frac{3}{16}$ of an inch smaller than the salmon bricks.

Pressed bricks or face-bricks are more uniform in size, as most of the manufacturers use the same sizes of molds. The prevailing size for pressed bricks is 8⅜ by 4⅛ by 2⅜ inches. Pressed bricks are also made 1½ inches thick and 12 by 4 by 1½ inches, those of the latter size being generally termed "Roman Bricks," or "Roman Tiles."

Pressed bricks should be made of such sizes that two headers and a joint will equal one stretcher, and it is also desirable that the length of a brick be made equal to three courses of bricks when laid. The National Brickmakers' Association in 1899 adopted 8¼ by 4 by 2¼ inches as the standard size for common bricks, 8⅜

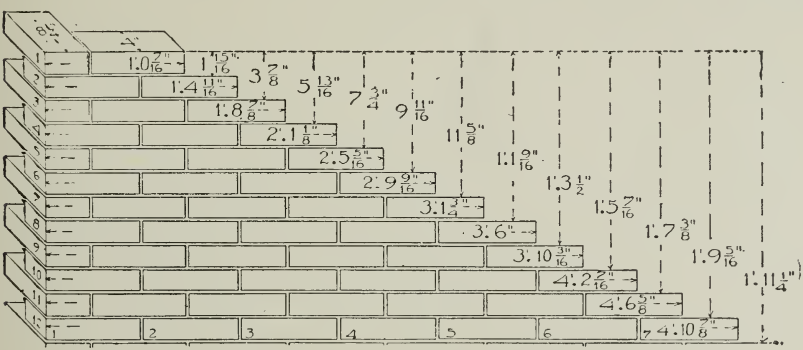


Fig. 164.—Diagram for 8¼ by 4 by 1¾-Inch Bricks, 3/16-Inch Joints.

by 4 by 2⅜ for face-bricks, 8½ by 4 by 2½ inches for paving bricks and 12 by 4 by 1½ inches for Roman bricks.

Figs. 163 and 164 are diagrams, reproduced through the courtesy of Gladding, McBean & Co., San Francisco.

Fig. 163 shows the average coursing and length of pressed bricks of dimensions 8¼ by 4 by 2⅜ inches, when laid with $\frac{3}{16}$-inch bed and head mortar joints.

Fig. 164 shows the same for a "Roman" shape of dimensions 8¼ by 4 by 1¾ inches, laid with joints of the same thickness.

As all bricks shrink more or less in burning, it is generally necessary to assort even pressed bricks into piles of different thicknesses in order to get first-class work.

The weight of bricks varies considerably with the quality of the clay from which they are made, and also of course with their size.

Common bricks average about 4½ pounds each, and pressed bricks vary from 5 to 5½ pounds each.

336 REQUISITES OF GOOD BRICKS.—1. Good building bricks should be sound, free from cracks and flaws and from stones and lumps of any kind, especially lumps of lime.

2. To insure neat work, the bricks must be uniform in size and the surfaces true and square to each other, with sharp edges and angles.

3. Good bricks should be quite hard and burned so thoroughly that there is incipient vitrification all through the bricks. A sound, well-burned brick will give out a ringing sound when struck with another brick or with a trowel. A dull sound indicates soft or shaky bricks. This is a simple and generally a sufficient test for common bricks, as bricks with a good ring are generally sufficiently strong and durable for any ordinary work.

4. A good brick should not absorb more than one-tenth of its weight of water. The durability of brickwork that is exposed to the action of water and frost depends more upon the absorptive power of the bricks than upon any other condition; hence, other conditions being the same, those bricks which absorb the least amount of water will be the most durable in outside walls and foundations. As a rule the harder a brick is burned the less water it will absorb. "Very soft, underburned bricks will absorb from 25 to 35 per cent of their weight of water. Weak, light red ones, such as are frequently used in filling in the interior of walls, will absorb from 20 to 25 per cent, while the best bricks will absorb only 4 or 5 per cent. A brick may be called "good" which will absorb not more than 10 per cent."*

337. STRENGTH OF BRICKS.—Good common bricks, suitable for piers and heavy work, should not break under a crushing load of less than 4,000 pounds per square inch; any additional strength is not of great importance, provided the bricks meet the preceding requirements. In a wall the transverse strength is usually of more importance than the crushing strength. For an unusually good common brick the modulus of rupture should be not less than 720 pounds per square inch, or, in other words, a brick 8 inches long, 4 inches wide and 2¼ inches thick should not break under a center load of less than 1,620 pounds, the brick lying flatwise and having a bearing at each end of 1 inch and a clear span of 6 inches. A

* Ira O. Baker, in "Masonry Construction."

brick which is considered very hard and first-class in every respect should carry 2,250 pounds in the middle without breaking, and bricks have been tested which carried 9,700 pounds before breaking.

338. SAND-LIME BRICKS.—*General Description.*—Sand-lime bricks were originally made of lime mortar, molded in brick form and hardened by exposure to the air. Such bricks are said to have been largely used in ancient times, and it is claimed that remains of such material are now in evidence and in a good state of preservation. It is known that they were formerly used in Europe in localities where other materials were not readily available, and that they have been used in some localities in this country during the last thirty years. The writer knows of several houses in Haddonfield, N. J., built of such bricks, generally with exterior surfaces plastered. One of them, however, said to be about twenty years old, has not been plastered, and an inspection showed the bricks to be in an excellent state of preservation.

Lime-mortar bricks harden by the absorption of carbonic acid gas from the air, which enters into combination with the lime, forming carbonate of lime. The hardening process requires several weeks' exposure under cover and the product has not virtues sufficient to commend it where other materials are available.

It was discovered in Germany about forty years ago that lime-mortar bricks could be hardened in a few hours under heat and pressure, and it was found later that the chemical reaction under the new process differs essentially from that just described, and that the percentage of lime can be greatly reduced.

The fundamental principles of sand-lime brick manufacture are now common property and only the details of manufacture are patentable. The commercial development of the industry dates back about twenty years in Europe, to about 1888, and only seven years in this country, to 1901. There are now, in 1908, over 300 factories in Germany, one of them with a capacity of 200,000 bricks per day. There are said to be now over 200 factories in operation in this country.

The economic features of the manufacture are such that the industry will doubtless be rapidly extended and the product come into more general use than in the past.

The Process.—Pure silica sand, mixed with from 5 per cent to 10 per cent of high calcium lime and a certain proportion of water, is molded under very high pressure into the form of bricks. These

are piled loosely on cars holding about 1,000 bricks each and placed in a steel cylinder large enough to hold from 10 to 20 cars. The cylinder is then closed, and steam is turned in and maintained at a pressure of from 120 to 135 pounds to the square inch for from 8 to 10 hours, when the cylinder is opened and the bricks removed, ready for use.

The tremendous pressure, which is said to be 100 tons on each brick, under which the bricks are formed, causes great density and a bringing of the component elements into close contact. The heat in the cylinder dries the bricks and causes a chemical reaction between the lime and a portion of the silica, forming calcium silicate, an insoluble and perfectly durable element, which bonds the remaining particles of the sand together. The small residue of uncombined lime combines, in the course of time, either with silica or with carbonic acid gas from the air, until no free lime remains. The bricks thus become harder and stronger with age.

In regard to the constitution of sand-lime bricks, Mr. Edwin C. Eckel, in the chapter on "The Production of Lime and Sand-lime Brick in 1906," in the Government Report on "The Mineral Resources of the United States for the Calendar Year, 1906," dated 1907 and published in 1908, writes as follows:

"In previous publications on the sand-lime brick industry the writer has stated that conclusive evidence had not yet been produced as to the constitution of the binding medium of sand-lime brick. The advocates of the new product not only claimed that a definite lime silicate was formed during processes of manufacture, but usually made the additional claim, by implication at least, that this silicate was the same as that which exists in Portland cement. The fact was overlooked that purely chemical means could not be relied on to prove these facts, if facts they were. Under these circumstances the writer, admitting his own incompetency to decide the question, believed it advisable to consider the matter unsettled, pending a decisive test by the only means possible—the petrographic microscope, used by one of the very few investigators intimately acquainted with the lime-silicate series.

"During the past year evidence has been submitted which seems conclusive. Mr. Frederick E. Wright, at the writer's request, examined several specimens of commercial sand-lime brick in the geophysical laboratory of the Carnegie Institution. Mr. Wright states that the binding material of these specimens is a hydrous lime

silicate somewhat akin to the familiar minerals of the zeolite group. The reactions involved in the formation of such a hydrous silicate from lime and sand in the presence of steam are simple and well known. It is to be noted, however, that these reactions are in no way comparable to those which take place during the processes of Portland cement manufacture and that the binding material of sand-lime brick is very different in composition and relationship from Portland cement clinker.

"It may safely be assumed, then, that a sand-lime brick as marketed consists of (1) sand grains held together by a network of (2) hydrous lime silicate, with probably (if a magnesian lime were used) some allied magnesian silicate, and (3) lime hydrate or a mixture of lime and magnesia hydrates. These three elements will always be present, and the structural value of the brick will depend in large part on the relative percentages in which the sand and the hydrates occur."

Quality.—The quality of the product depends mainly upon the selection and treatment of the sand and the lime. Pure silica sands, containing a large percentage of fine grains passing through screens of from 80 to 150 mesh, are preferable. Clay or kaolin are dangerous elements and should not be present in quantities of more than 5 per cent. The lime should be, preferably, high calcium lime, the magnesium silicates formed by impure limes not being as strong as calcium silicates. Some manufacturers use ready-hydrated lime, others hydrate the lime themselves, before mixing it with the sand, and others grind the quicklime, mix it with the sand and slaken it in the sand.

The other most important element affecting quality is the press. After pressing and before steaming, the bricks are very fragile and the press should be such that they are subjected to no shaking nor friction after the pressure is removed from the mold. Vertical clay brick-presses have been commonly used, but do not appear to be well adapted to the purpose. The rotary table-presses seem to be most successful.

Tests.—If the sand is reasonably clean and pure, and the lime finely divided; and if the bricks are sound and have a good metallic ring, they will stand weather exposure perfectly.

If a brick stands in still water for an hour and the moisture rises more than ½ an inch, it is not a first-class brick; if the moisture rises 2 inches, its use for facings is questionable; if the moisture

rises 3 inches, it should not be used on outside work of any importance.

Authentic tests* have been made for crushing, fire, frost and acid-resistance and for absorption, from which it may be concluded that under proper conditions of manufacture sand-lime bricks are produced having the following physical characteristics: Crushing strength, average, between 2,500 and 3,000 pounds per square inch, although some specimens in tests have shown over 5,000 pounds per square inch; modulus of rupture, average about 450 pounds per square inch; fire-resistance, but little inferior to that of fire-brick; frost-resistance, perfect; acid-resistance, very superior; absorption, from 8 per cent to 10 per cent in 48 hours; average for complete saturation, 15 per cent; reduction of compressive strength by saturation for absorption test, average 33 per cent.

The New York laws require for the absorption test, an average not exceeding 15 per cent, and no result over 20 per cent; for the modulus of rupture test, an average of 450 pounds per square inch, with no result below 350; for the compression test, an average of 3,000 pounds per square inch, with no result less than 2,500 pounds; and for the reduction of compressive strength after saturation, a loss of not more than one-third.

The bricks are square, straight and uniform in size and homogeneous in composition and density. They cleave accurately under the stroke of the trowel and present a weather surface with the good qualities of stone. They can be cut, carved or sand-blasted, are easily washed clean and show no efflorescence. These claims are well established for properly manufactured sand-lime bricks. It should be further stated that common bricks and facings are made in the same press, the only difference being in the selection of the materials and in the handling of the raw bricks. It is therefore claimed that a rational and homogeneous exterior wall structure is possible, since backings and facings may be built and bonded in even courses, with Flemish or other ornamental bonds.

Many factories, however, are producing inferior bricks and care should be taken in their selection.

Colors in Sand-lime Bricks.—The natural color is pearl gray, varying in warmth with the composition of the sand. Permanent

* See also "Tests Upon Sand-lime Bricks," made by Professor Ira H. Woolson, in November, 1905, at the Testing Laboratory, Columbia University, New York, for The National Association of Manufacturers of Sand-lime Products.

colors are produced by introducing mineral oxides with the raw materials in quantities varying according to the intensity of color desired; but as the oxides are foreign materials in the bricks, they affect the quality of the latter in proportion to the quantity used.

Production of Sand-lime Bricks.—In the year 1906 the product

TABLE XXV.

PRODUCTION OF SAND-LIME BRICKS IN THE UNITED STATES IN 1906, BY STATES.

State	Number of operating firms reporting	Common bricks		Front bricks		Fancy bricks		Blocks value	Total value
		Quantity (thousands)	Value	Quantity (thousands)	Value	Quantity (thousands)	Value		
Alabama, Kentucky, Mississippi and Tennessee	6	6,877	$51,079	1,276	$11,947	....	....	....	$63,026
Arkansas, Kansas, Minnesota, Nebraska, South Dakota and Texas	8	14,877	96,128	1,897	17,962	(a)	(a)	....	114,390
California	4	4,837	38,789	1,900	22,400	....	....	....	61,189
Colorado and Idaho	4	569	6,043	2,191	22,743	....	....	(a)	31,464
Delaware, Maryland and Virginia	4	9,403	61,719	(a)	(a)	....	....	....	67,119
Florida	8	11,678	83,306	(a)	(a)	....	....	....	89,306
Georgia	3	5,139	37,701	(a)	(a)	....	....	....	40,701
Illinois and Wisconsin	4	8,150	49,150	690	6,060	....	....	....	55,210
Indiana	6	17,077	84,361	326	2,474	(a)	(a)	....	86,880
Iowa	3	3,921	28,271	(a)	(a)	(a)	(a)	(a)	38,255
Michigan	11	27,281	162,879	1,796	12,022	(a)	(a)	....	174,921
New Jersey	3	6,520	49,143	....	....	....	....	(a)	50,143
New York	9	21,288	169,257	1,910	22,064	....	....	....	191,321
North Carolina	3	3,147	22,225	(a)	(a)	....	....	....	32,975
Ohio	4	1,232	7,049	(a)	(a)	....	....	....	10,184
Pennsylvania	7	6,673	50,211	978	12,710	....	....	....	62,921
Other States [b]	....	....	....	2,718	32,963	121	$3.473	$5,876	(c)
Total	87	148,669	997,311	15,682	163,345	121	3,473	5,876	1,170,005
Average value per M	....	....	6.71	....	10.42	....	28.70	....	....

[a] Included in other States.

[b] Includes all products made by less than three producers in one State, to prevent disclosing individual operations.

[c] The total of other States is distributed among the States to which it belongs in order that they may be fully represented in the totals.

Value of production of sand-lime bricks in the United States, 1903-1906.

Year	Number of plants	Value of product
1903	16	$155,040
1904	57	463,128
1905	84	972,064
1906	87	1,170,005

of the sand-lime brick industry was valued at $1,170,005, an increase of 20 per cent over the value, $972,064, in 1905. During 1906 the

value of the common building bricks made by this process averaged \$6.71 per thousand, as against \$6.59 in 1905. The front-bricks averaged \$10.42 per thousand, as against the 1905 average of \$11.02. Almost 90 per cent of the entire sand-lime product is marketed as common bricks, a result which could hardly have been anticipated when these bricks were first introduced into this country.

Detailed statistics for 1906 are presented in Table XXV.

339. CEMENT BRICKS.—Cement bricks are on the market in many places, and are used generally for facing purposes. Their characteristics are similar to those of concrete hollow blocks, and observations made of one product are generally true of the other. They are manufactured by machine, by hand or by power presses, and the following general principles should be observed.

Other conditions being equal, wet concrete mixtures tend to density, non-absorption and fineness of face:

Concrete attains its normal strength with its seasoning. Cement bricks should not be used earlier than two weeks, and should not carry considerable loads earlier than one month after the date of manufacture. Lean mixtures, however, require more time than rich mixtures.

Cement, sand and stone mixtures are stronger, denser and less absorbent, and require less cement than cement and sand mixtures. One part of cement to 4 of sand, or 1 part of cement to 3 of sand and 3 of aggregates from ¼ to ½ an inch in size, are given as minimum proportions of cement for cement bricks.

Much depends upon the character of the sand. It should contain both fine and coarse grains and should be clean and sharp.

By the selection of the color, shape and size of the aggregates and by the subsequent treatment, either by washing with acid or with water and stiff brushes, the faces of the bricks may be given various textures and colors. Various colors, also, are used in the cement.

Good cement bricks should stand the following minimum tests:*

Average minimum ultimate compressive strength, at 28 days, 1,000 pounds per square inch.

Average modulus of rupture at same age, not less than 150 pounds per square inch.

Absorption not over 15 per cent.

* "Standard Specifications for Concrete Hollow Blocks," prepared by E. S. Larned, C. E., for National Association of Cement Users

Cement bricks for any particular building should be carefully investigated and rigidly inspected for uniformity of quality.

For further discussions of concrete mixtures, concrete blocks, etc., see Chapter X.

2. BRICKWORK IN GENERAL.

340. In order to build any kind of brick structure so as to make a strong and durable piece of work, it is necessary to have a bed of some kind of mortar between the bricks. Brickwork, therefore, consists of both bricks and mortar, and the strength and durability of any piece of work depend upon the quality of the bricks, the quality of the mortar, the way in which the bricks are laid and bonded and whether or not they are laid wet or dry.

The strength and stability of a wall, arch or pier also depend upon its dimensions and the load it supports; but for the quality of the brickwork, only the above items need be considered.

The kinds and qualities of mortars used for laying brickwork are described in Chapter IV. The majority of the brick buildings in this country have been built with common white lime mortar, to which natural or Portland cement has been added. For brickwork below ground either hydraulic lime or cement mortar should be used. (See Articles 153, 164 and 200.)

The function of the mortar in brickwork is threefold, viz.:

1. To keep out wet and changes in temperature by filling all crevices.

2. To unite the whole into one mass.

3. To form a cushion to take up any inequalities in the bricks and to distribute the pressure evenly.

The first object is best attained by grouting, or thoroughly "flushing" the work; the second depends largely upon the strength of the mortar, and the third is effected principally by the thickness of the joints.

341. THICKNESS OF MORTAR JOINTS.—Common bricks should be laid in a bed of mortar at least $\frac{3}{16}$ and not more than $\frac{3}{8}$ of an inch thick, and every joint and space in the wall not occupied by other materials should be filled with mortar. The best method of specifying the thickness of joints is by the height of eight courses of bricks measured in the wall. This height should not exceed by more than 2 inches the height of eight courses of the same bricks laid dry.

As common bricks are usually quite rough and uneven, it is not always easy to determine the thickness of a single joint; but the variation from the specification in any eight courses that may be selected should be very slight. It is not uncommon to see joints $\frac{3}{4}$ of an inch thick in common brickwork, especially where the work is not superintended.

Pressed bricks, being usually quite true and smooth, can be laid with $\frac{1}{8}$-inch joints, and they are often so specified. A $\frac{3}{16}$-inch thickness is probably stronger, however, as it permits a more thorough filling of the joint.

It is impossible to completely fill $\frac{1}{8}$ or $\frac{3}{16}$-inch joints with mortar. Numerous small holes admit driving rains in streams. Efflorescence can in many cases be traced to holes in the facing.

Very little first-class work is now done with fine joints, the tendency being toward wall surfaces with character and texture. The joints should be thick enough to bring the facings to an even bed with the backings, and to allow them to be bonded with the headers, and they may be from $\frac{1}{4}$ of an inch to 1 inch in thickness. They are frequently recessed from $\frac{1}{8}$ to $\frac{3}{8}$ of an inch. The horizontal joints may be recessed with the vertical joints flush; or the horizontal joints may be thick and the vertical joints thin.

342. LAYING BRICKS.—A. *Common Bricks.*—The best way to build a brick wall is, first, to lay the two outside courses by spreading the mortar with a trowel along the outer edge of the last course of bricks, to form a bed for the bricks to be laid, scraping a dab of mortar against the outer vertical angle of the last brick laid; and then to press the bricks to be laid into their places with a sliding motion, forcing the mortar to completely fill each joint.

Having continued the two outer courses of bricks to an angle or opening, the space between the courses is filled with a thick bed of soft mortar and the bricks pressed into this mortar with a downward diagonal motion, so as to press the mortar up into the joints. This method of laying is called "shoving." If the mortar is not too stiff, and is thrown into the wall with some force, it will completely fill the upper part of the joints, which are not filled by the shoving process. A brick wall laid up in this way is very strong and difficult to break down. This class of work is

commonly called "shoved work." It is done only under constant supervision and is more expensive than ordinary brickwork.

A very common method of laying the inside bricks in a wall is to spread a bed of mortar and on this lay the dry bricks. If the bricks are laid with open joints and thoroughly slushed up it makes very good work; but unless the men are carefully watched the joints are not filled with mortar and the wall is not as strong as when the bricks are shoved.

Grouting.—Another method of laying the inside bricks is to lay them dry on a bed of mortar, as described above, and then to fill all the joints full with a very thin mortar. This is called "grouting," and, while it is condemned by many writers, it is contended by persons having large experience in building that masonry carefully grouted, when the temperature is not lower than 40 degrees Fahr., will give the most efficient result; and the author knows from

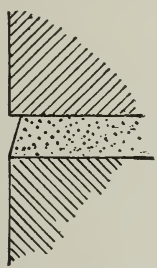


Fig. 165.—Struck Joint with Drip.

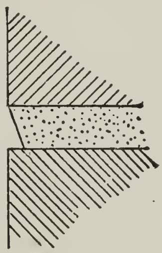


Fig. 166.—Struck Joint without Drip.

actual experience that when properly done it makes very strong work. Many of the largest buildings of New York City have grouted walls. The Mersey Docks and Warehouses at Liverpool, England, one of the greatest masonry works in the world, were grouted throughout. No more water than is necessary to make the mortar fill all the joints should be used, and grouting should not be used in cold or freezing weather. Grouting is especially valuable when very porous bricks are used. (See Article 206, "Grout," in Chapter IV.)

Striking the Joints.—For inside walls that are to be plastered the mortar projecting from the joints is merely cut off with the trowel flush with the face of the walls. For outside walls and inside walls, where the bricks are left exposed, the joints should be "struck" as in Fig. 165. This is done with the point of the trowel, by hold-

ing it obliquely. Fig. 166 is the easiest joint to make, and is the one generally made unless that shown in Fig. 165 is insisted on. For inside work it makes no particular difference which joint is used, but for outside work Fig. 165 is much more durable, as the water will not lodge in it and soak into the mortar, as will be the case when it is made as in Fig. 166.

When "struck joints" are desired they should always be specified, otherwise the brick-mason may claim that he is not obliged to strike them.

B. *Face-bricks.*—(See also Article 341.) Face-bricks are usually laid in mortar made of lime putty and very fine sand, often colored with a mineral pigment. (See also Articles 150, 216, 217 and 218.) The joints should not exceed $^3/_{16}$ of an inch, except in cases where a horizontal effect is desired, when the horizontal joints are made $\frac{1}{4}$ of an inch and the vertical joints as narrow as possible. For very fine work the joints are sometimes kept down to $\frac{1}{8}$ of an inch. The joints should be carefully filled with mortar and either ruled at once with a small jointer or else raked out and left for pointing. In very particular work a straight-edge is held under the joint and the jointer drawn along the top of it, thus making a perfectly straight joint. This is called "ruled work." In laying the soffits of arches and vaults with face-bricks, the joints cannot be finished until the centers are removed; the joints should therefore be not quite filled with mortar, and should be raked out and pointed after the centers are removed.

Many makes of pressed bricks and some hand-made bricks have one or more depressions in the larger surfaces to give better keys to the mortar. When the depressions are on one side of a brick only, that side should be uppermost.

When building with face-bricks, a piece of brickwork at least 2 feet 6 inches long should be built up, as a sample piece, in an out-of-the-way place as soon as the first lot of bricks is delivered; and all stone or terra-cotta work should be made to conform absolutely to this brickwork.

Sorting.—Pressed bricks, even from the same kiln, generally vary in size and shade, the darker bricks being often $\frac{1}{16}$ of an inch thinner than the lighter bricks and also shorter. If, therefore, a perfectly uniform color is desired the bricks must be sorted into

piles, so that each lot will be of the same shade, and each shade laid in the building by itself. The changes between the different shades should occur, where possible, at string-courses or at angles in the building. Many architects, however, consider that handsomer and brighter walls are secured by mixing the different shades, so that hardly two bricks of exactly the same shade come together. If the mixing is well done the general tone of a wall at a distance will be uniform. With colored bricks this haphazard method undoubtedly gives the most artistic and sparkling effects.

Circular Work.—For circular walls, faced with pressed bricks, the latter should be made of the same, or of very nearly the same, curvature as that of the wall. Many manufacturers of pressed bricks carry circle bricks of different curvatures in stock, and bricks of any curvature can be made to order.

When circle bricks cannot be obtained, straight bricks may be used for curvatures with a radius of 12 feet or over, and for shorter radii half bricks or headers should be used.

343. WETTING BRICKS.—Mortar, unless very thin, will not adhere to dry, porous bricks, because they rob the mortar of its moisture, preventing its proper setting. On this account bricks should never be laid dry, except in freezing weather; and in hot, dry weather it is impossible to get the bricks too wet. When using very porous bricks the wetting of them is of more consequence in obtaining a strong wall than any detail of the operation. As wetting the bricks greatly increases their weight and consequently the labor of handling them, besides making it harder on the hands, masons do not like to wet them unless they are obliged to, and it should always be specified and insisted upon by the superintendent, except in freezing weather.

Pressed bricks cannot very well be laid dry, and the masons generally wet them for their own convenience; but they will often tell all sorts of stories to escape wetting the common bricks.

344. LAYING BRICKS IN FREEZING WEATHER.—Brickwork in lime mortar should not be laid in freezing weather. If the temperature is below 40 degrees Fahr. and liable to fall below 32 degrees at night, salt should be mixed with the mortar, the bricks heated before laying and the top of the wall covered with boards and straw at night. If the mortar in any part becomes frozen, the

courses in that part should be removed and cleaned before they are used again.

Cement mortar is not injured by frost after the first set has taken place. It may be used in freezing weather if precautions are taken by heating the materials, by protecting the walls or by the use of salt, to prevent freezing before this set has taken place; otherwise a sudden thaw is liable to soften the mortar and cause settlement. But it is not considered good practice to attempt to lay bricks in temperatures below from 17 degrees to 23 degrees Fahr. unless the walls are in warmed enclosures.

Lime in the mortar retards the setting, and mixing the mortar with hot water hastens the setting and keeps the walls warm longer. Salt in amount from 2 per cent to 8 per cent of the water by weight prevents frost, but is objected to by many on account of a resulting tendency to efflorescence. Higher percentages retard setting and reduce the strength at short periods. In any case the bricks should not be freezing cold nor wet, and they must be clean.

For the effect of freezing on mortar see Articles 213 and 214.

345. PROTECTION FROM STORMS.—Moisture without frost does not injure the strength of brickwork, but if rain strikes the top of a wall it will wash the mortar out of the joints and stain the face of the wall.

The excessive wetting of walls is also injurious, as it takes a long time for them to dry out, and they are likely never to dry to a uniform color. For this reason the tops of the walls should always be protected at night, or, when leaving off work, by boards placed so as to shed the water.

346. ORNAMENTAL BRICKWORK.—American practice in the design of ornamental brickwork has been derived chiefly from examples in England and northern Italy, and it is well to note that the long continued cold weather in our northern localities demands a treatment of such work very different from the practice in those countries.

The upper surfaces of copings and brick projections are the sources of serious danger to the continued good appearance and to the permanency of the walls in which they occur, unless protected by overhanging coverings with drips. Through the action of the frost the mortar in the exposed joints finally loses its hold upon the bricks and permits moisture to follow the joints to the interior of the walls. Thence the water is likely to percolate to lower levels

and to the outside surfaces, depositing the chemicals dissolved in its path upon the faces of the walls in stains or efflorescence, decomposing the mortar in the joints and ultimately destroying the walls.

The ornamental effects to be obtained by the varied uses of bricks are exceedingly numerous. First, there are the constructive features, such as arches, impost courses, pilasters, belt-courses and string-courses, cornices and panels; then there is a large field for design in surface ornament, by the use of bricks of different hues, tints or shades, laid so as to form patterns.

For the constructive features both plain and molded bricks may be used, although only very plain effects can be produced with plain bricks alone.

In nearly all of our large cities, and especially in those near which

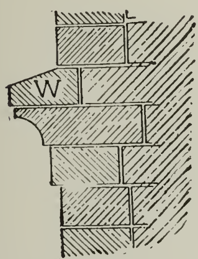


Fig. 167.—Brick Belt-course with Wash.

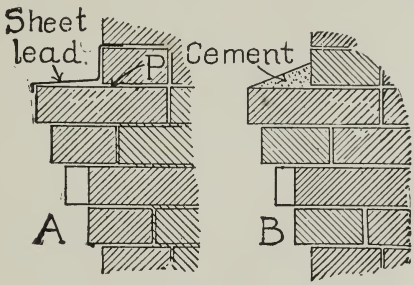


Fig. 168.—Brick Belt-courses.

pressed bricks are manufactured, a great variety of molded bricks can be obtained, by means of which it is possible to construct almost any moldings, belt-courses, etc., that may be desired.

Belt-courses and cornices, and in fact any details of molded work built of bricks, are much cheaper than the same moldings cut in stone.

In designing brick details the projections should be kept small.

The tops of the belt-courses should have washes on the top surface, as shown in Fig. 167.

The top course, *W*, should be laid with stretchers when the projection is not over 3 inches, in order to reduce the number of end joints; and the bricks should also be laid in cement mortar, so that that which is in the end joints will not be washed out.

If *W* is a stretcher course at least every other brick in the course below should be a header.

If bevelled bricks cannot be obtained for the top courses, and if

plain bricks must be used, the upper surface should be protected by sheet-lead built into the second joint above it, as shown in Fig. 168 *A;* or the top of the bricks may be plastered with Portland cement, as shown in Fig. 168 *B.** Unless some such precautions are taken to protect the tops of the projecting bricks from excessive moisture, the rain-water will after a while soften the mortar in the joints, *P,* and penetrate the wall. The end joints in the belt-courses are always liable to be washed out.

Belt-courses and cornices should always be well tied to the walls by using plenty of headers or iron ties. The tops of the walls should also be well anchored to the rafters or ceiling joists by iron anchors, as the projection of a cornice tends to throw a wall outward.

In using molded bricks in string-courses and cornices, it is more economical to use bricks that can be laid at stretchers, as it takes

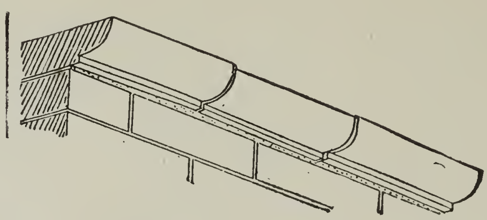


Fig. 169.—Molded Brick Course, Showing Distortion.

a smaller number of stretchers than of headers to fill given lengths, and the cost is the same.

One of the greatest objections to brick moldings is the difficulty in getting them perfectly straight and true. Nearly all molded bricks become more or less distorted in molding and burning, so that when laid the abutting ends do not match evenly, and moldings present an appearance like that shown in Fig. 169.

Some makes of bricks, however, are quite free from these defects, and before selecting molded bricks to be used in this way the architect should endeavor to ascertain what makes give the truest and most perfect work.

By being very careful in laying the bricks so as to average the defects, and by ruling the joints, the effects of the distortion may be largely overcome. Distortion is more apt to show with stretchers than with headers.

347. BRICK CORNICES.—Brick bed-molds for wood or iron

* A temporary expedient, which must be renewed from time to time.

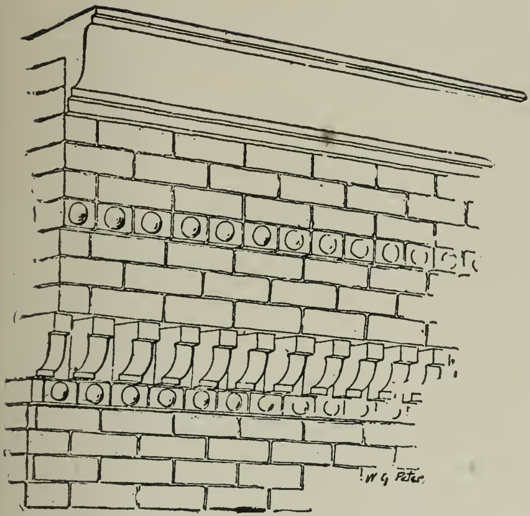


Fig. 170.—Design for Molded Brick Cornice.

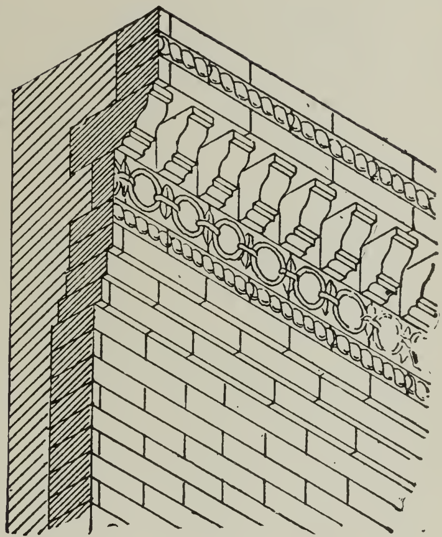


Fig. 171.—Design for Molded Brick Cornice.

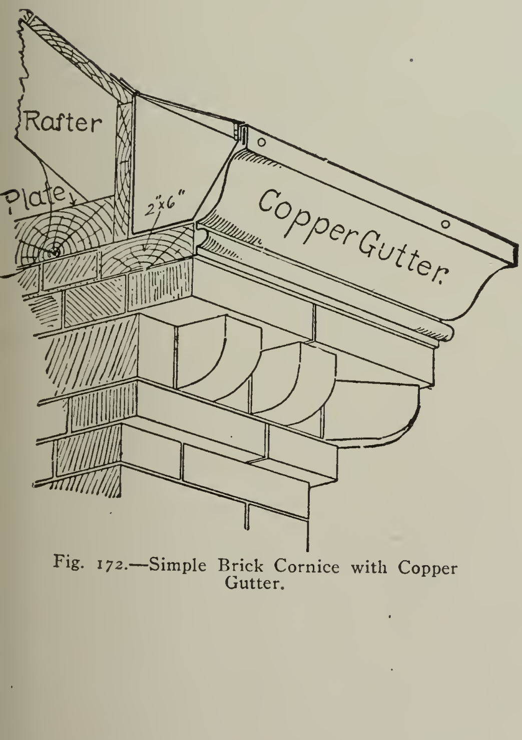


Fig. 172.—Simple Brick Cornice with Copper Gutter.

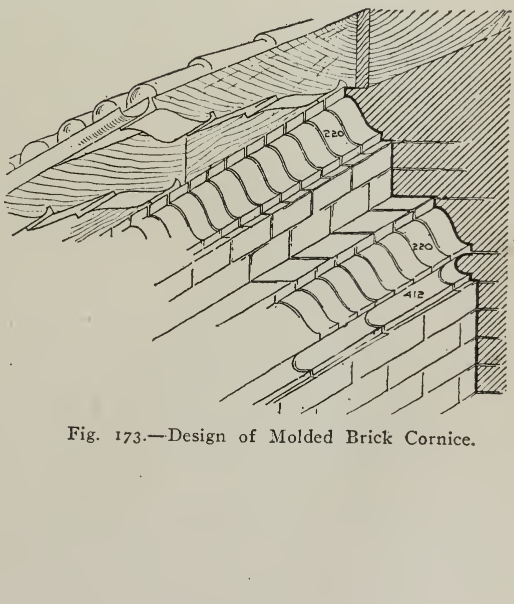


Fig. 173.—Design of Molded Brick Cornice.

cornices may be designed in wide variety and with excellent effect. Whole cornices may be designed in brick, although only a comparatively slight projection is practicable, and metal or terra-cotta coverings with efficient overhanging drips are essential.

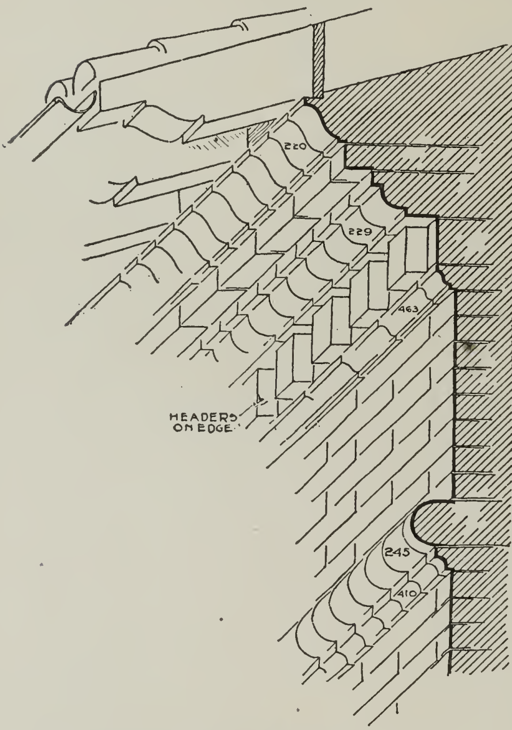


Fig. 175.—Design for Molded Brick Cornice.

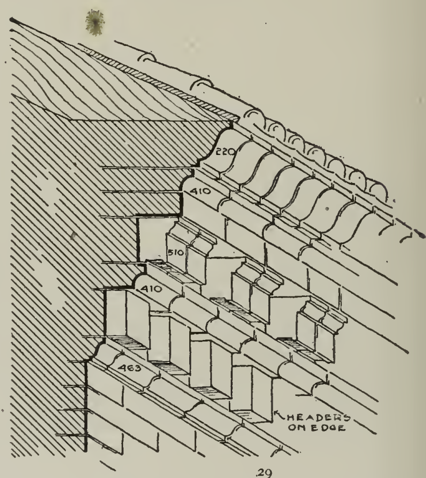


Fig. 174.—Design for Molded Brick Cornice.

Figs. 170 and 171, taken from *The Brickbuilder*, are suggestions for molded brick cornices for three and four-story buildings. Fig. 172 shows a section of a simple brick cornice that the author has used on brick churches having pitched roofs.

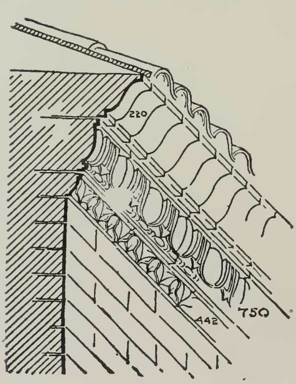


Fig. 176.—Design for Molded Brick Cornice.

All brick walls or cornices should be capped by projecting copings of metal, terra-cotta or stone, provided with a hollow drip to throw off the water.

For brick cornices a copper or galvanized-iron crown-mold, such as is shown in Fig. 170, is very appropriate. The metal should be carried over the top of the wall, if a parapet, and down 5 inches at the back.

Figs. 173, 174, 175 and 176 show additional designs for brick cornices, reproduced through the courtesy of the Eastern Hydraulic-press Brick Company, Philadelphia, from "Suggestions in Brickwork." Figs. 173 and 175 show overhanging eaves which may or may not be used. The height of the brick cornice in Fig. 173 is 16 inches and the projection 13 inches; in Fig. 174 the height is 24 inches and the projection 14 inches; in Fig. 175 the height is 42 inches and the projection 14 inches; and in Fig. 176 the height is 12 inches and the projection 7 inches.

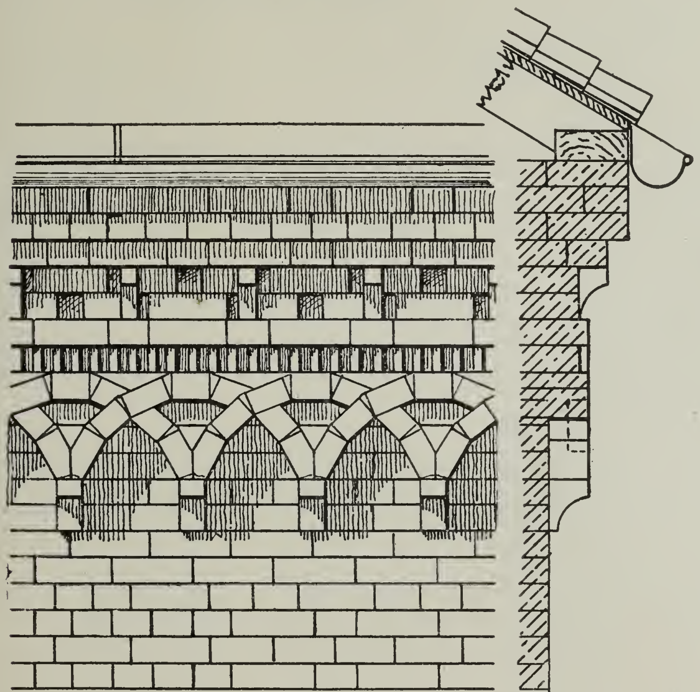


Fig. 177.—Brick Cornice Modelled After Cornice of Baptistry of San Stefano, Bologna, Italy.

Fig. 177 is a design modelled closely after the cornice of the Baptistry of San Stefano, Bologna, Italy.

If the walls terminate as shown in Fig. 171 the upper courses should be laid in cement mortar and the tops well plastered with Portland cement at the same time the bricks are laid. This will protect the walls for several years, but is not as lasting as terra-cotta or metal.

348. SURFACE PATTERNS.—Surface patterns, or diaper

work, are very common in brick buildings in Europe, and they have been introduced to a considerable extent in this country.

Their chief object is to give variety to a plain wall space. When used in exterior walls they should not be so marked as to make the

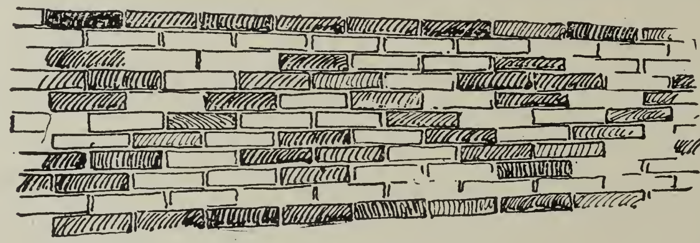


Fig. 178.—Simple Brick Diaper Pattern for Frieze.

pattern insistent and thus interfere with other features of the building.

Sorting the bricks into light and dark shades, or varying the color of the mortar in which the pattern is laid, is usually sufficient for any surface decoration, the best success in this class of decoration being obtained by using comparatively simple designs and quiet contrasts of color.

If different colors are used the greatest care must be exercised in

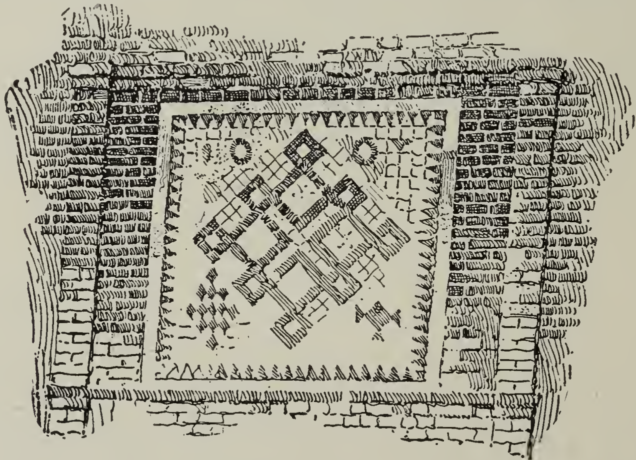


Fig. 179.—Surface Pattern for Brick Panel.

their selection, and even with care and thought it is not granted to all architects to use color successfully.

One of the best opportunities for the use of color lies in the direction of pattern work for frieze-courses and band-courses.

Fig. 178 shows a simple brick diaper for a frieze, and Figs. 179 and 180 an ornamental panel and a chimney, the latter designed by Mr. H. P. Marshall.

Fig. 181 shows some diagrams which suggest possibilities of arrangement in band patterns, as indicated in the upper drawings,

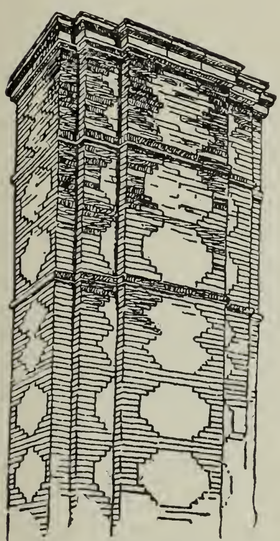


Fig. 180.—Brick Chimney Panels.

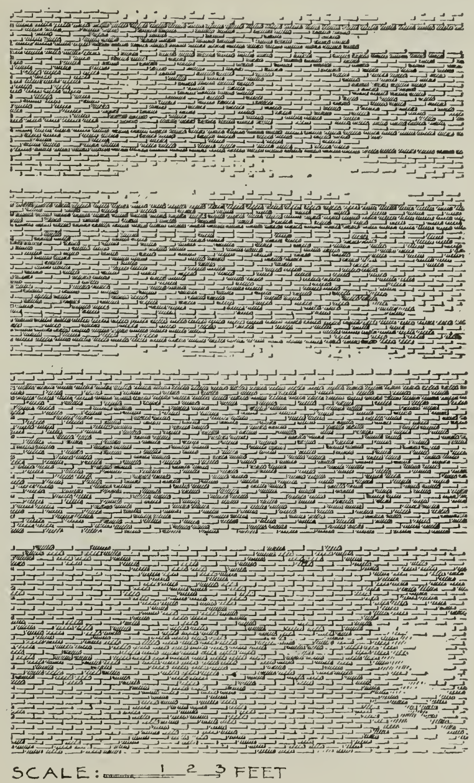


Fig. 181.—Brick Band and Diaper Patterns.

and in diaper work, as indicated in the two lower drawings. These drawings are reproduced through the courtesy of the Eastern Hydraulic-press Brick Company, Philadelphia, from "Suggestions in Brickwork." All the designs in Fig. 181 are made by the use of stretchers only. Proportions and sizes of designs can be materially changed by the use of headers. The lower pattern suggests three different shades of bricks. The coloring is optional, but strong contrasts should be avoided.

Fig. 182 is an interesting example of mediæval Italian brickwork

from San Stefano, Bologna, Italy. The patterns are partly filled with pieces of stone and terra-cotta.

Fig. 183 is an example of English wall pattern in brickwork, the figure being in bricks of a slightly lighter shade than that of the wall itself. The detail is from a residence in North Mymms, Hertfordshire, England.

Surface patterns should generally be flush with the walls. When

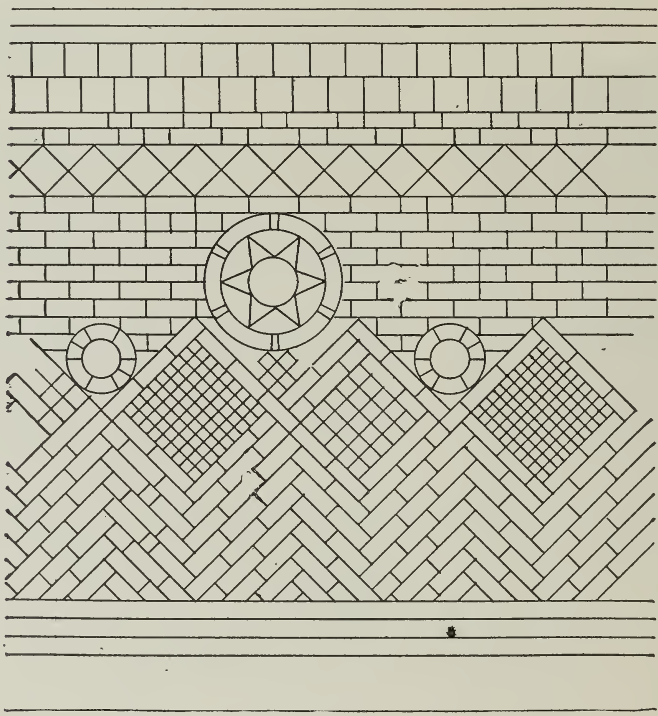


Fig. 182.—Brick Wall Surface from San Stefano, Bologna, Italy.

used as in Fig. 180 the pattern may project ¼ inch from the surface or panels.

Diaper work may also be used with good effect on interior brick walls of waiting-rooms, corridors, public baths, etc.

3. CONSTRUCTION OF BRICK WALLS.

349. GENERAL CONSIDERATIONS.—The proper construction of a brick building involves many things besides the mere laying of one brick on top of another with a bed of mortar between. The manner of laying or bedding the bricks and the general methods

of doing the work having been considered, we will next consider the details of construction required to obtain strong and durable walls, and the precautions to be taken to prevent settlements and cracks and to adapt the work to the purposes for which it is intended.

Aside from the quality of the materials and the character of the work, the bonding of a wall has the most to do with its strength.

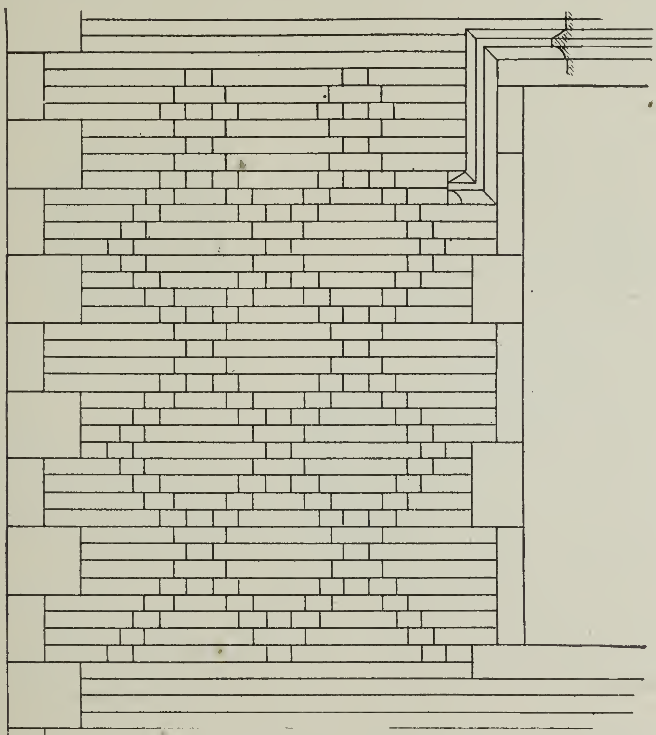


Fig. 183.—Detail from Residence, North Mymms, Hertfordshire, England.

350. BOND IN BRICKWORK.—Bond in brickwork is the arrangement of the bricks adopted for the purpose of tying all parts of a wall together by means of the weight resting on the bricks, and also for the purpose of distributing the effects of a concentrated weight over an ever-increasing area.

Common Bond.—A brick laid with its long sides parallel to the face of the wall is called a "stretcher," and with its long sides at right-angles to the face of the wall a "header." Common brick walls in this country are almost universally built by laying all the bricks as

stretchers for from four to six courses, and then by laying a course of headers as shown in Fig. 184. When a wall is more than one brick in thickness, the heading courses should be arranged as at either *A* or *B*, Fig. 185. For first-class work such a wall should be bonded with a heading course every sixth course.

Plumb Bond or Diagonal Bond.—This is sometimes called "American bond," and is generally used when the walls are faced with pressed bricks. All the face-bricks are laid as stretchers with the joints plumb above each other from bottom to top of walls, as shown at *A*, Fig. 186. The bonding of the face-bricks to the common bricks

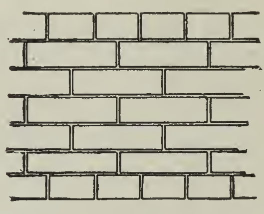


Fig. 184.—Common Bond.

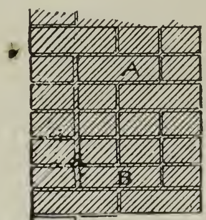


Fig. 185.—Cross-section of Common Bond Brick Wall.

is accomplished by clipping off the back corners of the face-bricks in every sixth or seventh course and by laying diagonal headers behind, as shown at *B*, Fig. 186. This does not make as strong a tie as the use of regular headers, but if carefully done it appears

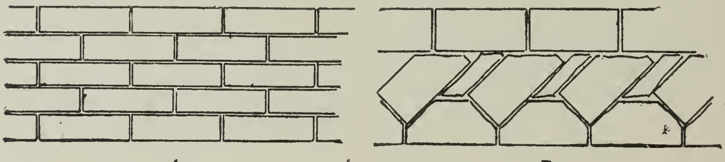


Fig. 186.—Plumb Bond.

to answer for some purposes. Very often where this bond is used only one corner of each face-brick in the outside course is clipped, so that only half as many diagonal bricks, or headers, as are indicated in Fig. 186, are used. This of course does not make as strong a bond as when both of the back corners are clipped. In walls exceeding one story in height the architect should see that both corners are clipped. The strongest method of bonding for face-bricks is by the Flemish or cross bonds, described further on. The objection to these bonds, however, is the increased expense occasioned by using so many face-brick headers, and also the fact that the face-

bricks and common bricks cannot usually be laid so as to come out to exactly the same heights. In this case it is necessary to clip the common bricks if face-brick headers are used in every course, or even in every third or fourth course.

Face-bricks, when laid as in Fig. 186, are often tied to the backing, as shown in Fig. 187, by pieces of galvanized-iron or tin, which have their ends turned over stiff wires, about 4 inches long. The wires are not absolutely essential, but should always be used in first-class work. Still better ties for bonding face-bricks to the backing are the Morse wall-ties, shown in Fig. 188, or similar ties.

These ties are made from $^5/_{32}$ and $\frac{1}{8}$-inch galvanized-steel wire, 7, 9, 12 and 16 inches in length. The $^5/_{32}$-inch wire is used for ordinary pressed brickwork, and the $\frac{1}{8}$-inch size for very closely

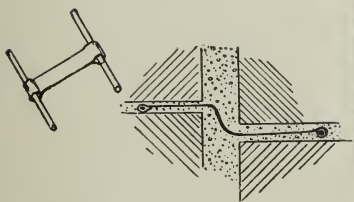


Fig. 187.—Metal Tie for Face-brick and Backing.

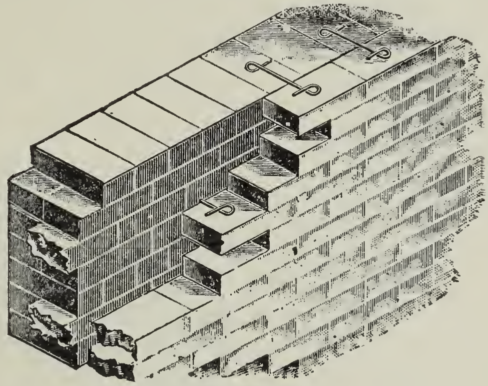


Fig. 188.—Morse Wall-tie for Face-brick and Backing.

laid work. These ties, or similar ties, are now very extensively used in the eastern portion of the country.

One advantage obtained in using metal ties is that it is not necessary to have the joints in the face-work and backing on the same level, as the ties can be bent to conform to the differences in level, as shown in Fig. 187. Face-bricks bonded in this way should be tied at least every fourth course with one tie to each face-brick.

The common American practice of laying all the facing bricks as stretchers, with $\frac{1}{8}$-inch joints, is peculiar to this country, and is recognized the world over as thoroughly bad, constructively and artistically. Such facings are mere veneers and contribute but little to the strength of walls. The building laws of New York, San Francisco and some other cities require that they be ignored in com-

puting the necessary thickness of exterior walls; while the Boston law requires full headers and prohibits "diagonal bond."

"This class of work is laid up with joints which are too thin to be of use constructively, and which rob the work of all character, giving to it a hard, dry, sleek appearance, that appeals to no artistic instinct."*

The better method is to lay the facings on even beds with the backings and to bond with headers in such an arrangement as will best suit the architectural purposes of the designer. Thick joints and headers give character and texture to the wall surfaces, and every different arrangement of headers has its own decorative value. Figs. 189,† 190† and 191 are good examples.

"The supposed economy of the common method . . . . . . will be found, upon examinaton, not to be economical, but the reverse."‡ The principal additional expense in bonded work is in the labor. Our bricklayers are generally not accustomed to such work and take more time per square foot of wall.

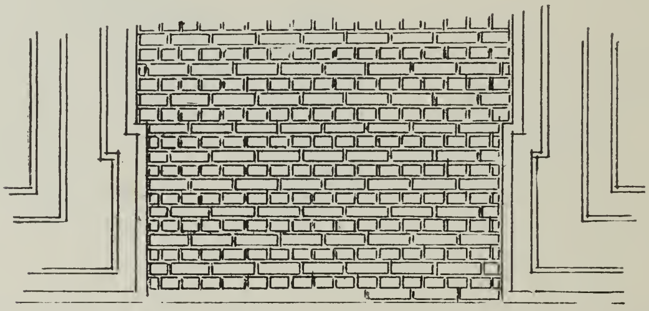


Fig. 189.—Brickwork for Singer Building, New York. Joints Recessed Three-eighths of an Inch.

English Bond.—Fig. 192. This is a method of bonding much used in England, and consists of alternate header and stretcher courses. It is probably the strongest method of bonding common bricks, but is not applicable where face-bricks are used in the usual American manner. It does not make very attractive work, and is scarcely ever used in this country.

Flemish Bond.—This is shown in Fig. 193, and consists of alter-

* Mr. Ernest Flagg, in *The Brickbuilder*, Vol. 7, No. 12.

† These and other drawings are reproduced through the courtesy of *The Brickbuilder*. For Figs. 189 and 190 see Vol. 7, No. 12, pages 259 and 260. Fig. 189 shows brickwork in the Singer building, New York; Fig. 190 shows brickwork in a house for the Clark estate.

‡ Ernest Flagg, *The Brickbuilder*, Vol. 7, No. 12.

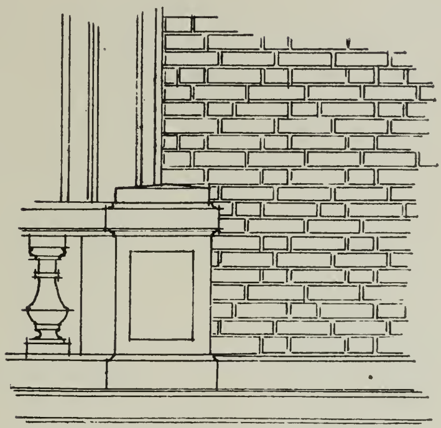


Fig. 190.—Brickwork of House for Clark Estate.

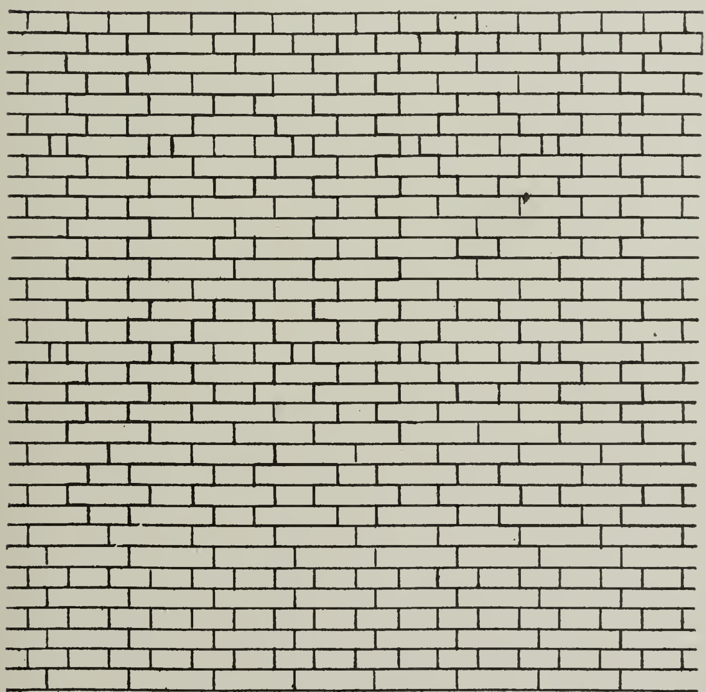


Fig. 191.—Brickwork. Interior in St. Bartholomew's Church, Brighton, England.

nate headers and stretchers in every course, every header being immediately over the middle of a stretcher in the course below. Closers (*a*) are inserted in alternate courses next to the corner headers to form the necessary lap. This makes a very strong bond. A modification of this bond, which consists in laying every fifth course with alternate headers and stretchers, is sometimes adopted. It

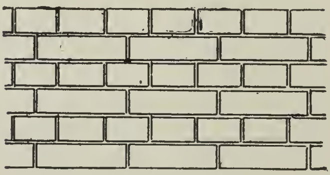


Fig. 192.—English Bond.

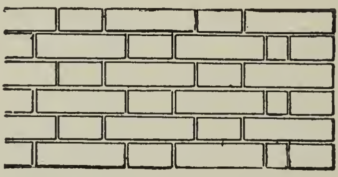


Fig. 193.—Flemish Bond.

makes stronger work than the diagonal bond and looks about as well.

English Cross Bond.—This is a variety of English bond and is said to be much used in Holland, its name being suggested by the appearance of the surface, on which the bricks seem to arrange themselves into St. Andrew's crosses. It differs from ordinary English bond only in having the stretchers of the successive stretcher courses break joint with each other, as well as with the headers in the adjoining courses on the face of the wall, as shown in Fig. 194. This makes a much better-looking wall than results from the ordinary English bond.

351. HOOP-IRON BOND IN BRICKWORK.—Pieces of hoop-iron are often laid flat in the bed-joints of brickwork to increase its longitudinal tenacity and to prevent cracks due to unequal settlement. The ends of the iron should be turned down about 2 inches and inserted in the vertical joints. Nothing less than No. 18 iron should be used, and the holding power of the ties may be greatly improved by dipping them in hot tar and then covering them with sand. Hoop-iron bond is strongly to be recommended for strengthening brick arches and the walls above them, the walls of towers, the joining of interior with exterior walls, etc. Twisted iron bars are still better for this purpose.

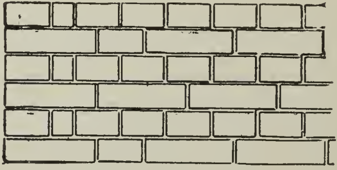


Fig. 194.—Cross Bond.

352. ANCHORING BRICK WALLS.—Although this belongs

more especially to the carpenter's work, it is mentioned here as a very important detail in securing the stability of walls and in preventing any from inclining outward.

Brick walls should be tied to every floor at least once in every 6 lineal feet, either by the use of iron anchors, built solidly into the walls and spiked to the floor joists, or by means of box-anchors or joist-hangers.

The forms of iron anchors commonly used for this purpose are

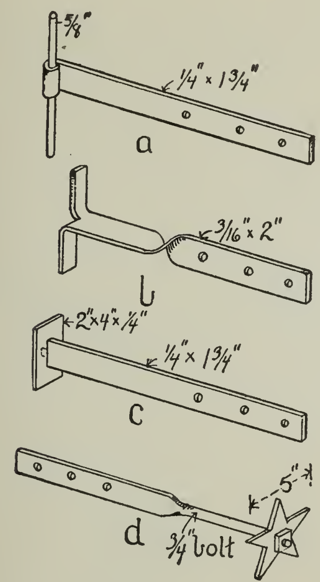


Fig. 195.—Iron Anchors for Floor Joists.

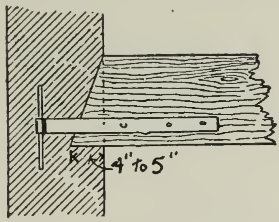


Fig. 196.—Joist Anchored to Brick Wall.

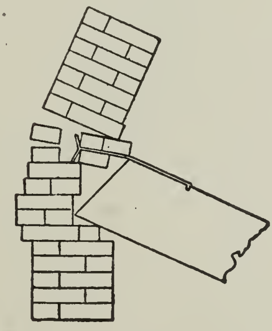


Fig. 197.—Destructive Effect of Anchor at Top of Joist.

those shown in Fig. 195, the one shown at *a* being the most common, and about as good as any. The anchor shown at *b* answers the purpose just as well, but costs a little more. Anchors like *a* and *b* are spiked to the sides of the floor joists and built into the walls, as shown in Fig. 196.

In the case of side or rear walls, where appearances are not of much consequence, it is better to have the anchors pass clear through them, with plates on the outside, as such anchors take much better hold on walls than is possible when they are built into the middle parts only. The form of the cheapest anchor for this purpose

is that shown at *c*. The anchor has a thin plate of iron dowelled and upset on the outer end. Anchors of this style may be used also for building into the middle of the walls.

Where the ends of girders are to be anchored, or where particularly strong anchors are desired, the form shown at *d* is undoubtedly the best. These anchors are made from ¾-inch bolts, flattened out for spiking to the joists and provided with cast-iron star washers. An anchor of this kind possesses the advantage of having a nut on the outer end, which can be tightened up if desired after the walls are built.

All of these anchors should be spiked to the sides of the joists or girders, *near the bottom*, as shown in Fig. 196. The nearer an anchor is placed to the top of a joist the greater will be the destructive effect on the wall by the falling of the joist, as shown in Fig. 197.

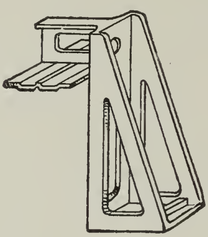


Fig. 198.—Duplex Wall-hanger.

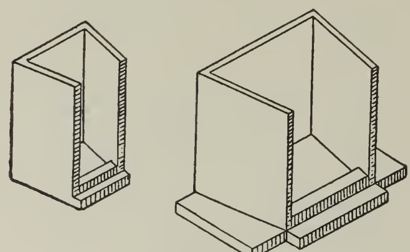


Fig. 199.—Goetz Box-anchors.

For anchoring walls that are parallel to the joists, the anchors must be spiked to the tops of the joists; and either they should be long enough to reach over two joists, or pieces of 1¼-inch boards should be let into the tops of three or four joists and the anchors spiked to them.

The objection to all of these anchors is that in case the beams fall during a severe fire or from any other cause, they are apt to pull the walls over with them. To overcome this objection, as well as to secure other advantages, the Duplex wall-hangers, shown in Fig. 198, and the Goetz box-anchors, shown in Fig. 199, have been invented. These devices hold the timbers by means of ribs or lugs gained into their lower surfaces. The anchoring is perhaps not as efficient as is secured by the anchors shown in Fig. 195, but it is ample for all ordinary conditions, as *every* joist is anchored when these devices are used.

These devices offer also the additional advantages of not weakening the walls, while they increase the bearings of the timbers and reduce the possibility of dry rot to a minimum. They also permit of easily replacing the joists after a fire.

A stronger form of the Duplex is the wall-hanger shown in Fig.

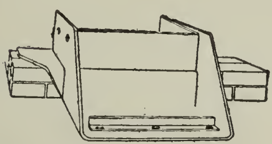


Fig. 200.—Stronger Form of Duplex Wall-hanger.

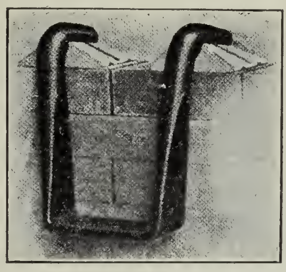


Fig. 201.—Goetz Wall-hanger.

200. The Goetz Box-anchor Company also make wall-hangers of a form shown in Fig. 201, which have the advantage of great simplicity and strength. The "Truss-coN" wall-hangers, Fig. 202, are well-designed single-plate pressed-steel hangers which have satisfied very high tests for strength.

Wall-hangers of the general types illustrated in Figs. 198, 200,

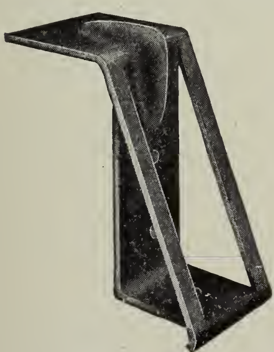


Fig. 202.—The "Truss-coN" Wall-hanger.

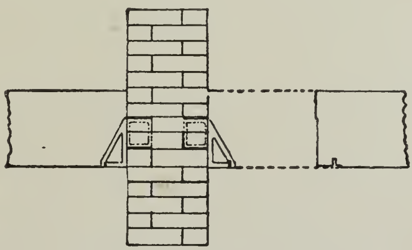


Fig. 203.—Beam Anchored to Party-wall with Wall-hangers.

201 and 202 are especially desirable for party-walls and partition walls, as they obviate the necessity of building the beams into the walls and permit the walls to be as solid at the floor levels as in other portions. (See Fig. 203.)

The importance of anchoring the joists to the walls, and thus preventing the latter from being thrown outward either from settlement in the foundation or from pressure exerted against the insides of the walls, is very great, and should not be overlooked by the architect. Many walls, which might have been saved by proper anchoring, have either fallen, or have had to be rebuilt.

353. CORBELLING BRICK WALLS FOR FLOOR JOISTS. —In some localities it is the custom to form ledges to support the floor joists by building continuous corbels of three or more courses. This is done to prevent the ends of the floor timbers from weakening the walls; for, of course, wherever wooden timbers are built into them, they make the section or bearing area of the walls smaller by just the amount of space taken up by the timbers; and in partition walls this is very considerable.

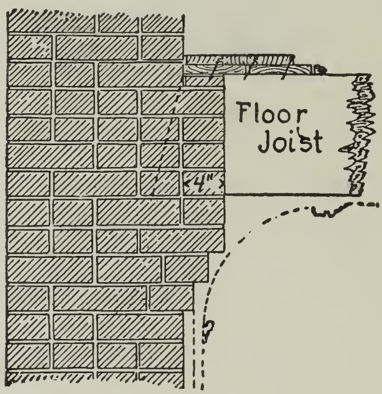


Fig. 204.—Brick Corbel for Floor Joists.

The Chicago Building Ordinance provides that all walls, 16 inches or less in thickness, shall have ledges of the thickness of the furring, lath and plaster to support the floor joists; and in all cases where ledges are built they are to be carried to the tops of the joists, as shown in Fig. 204.

When walls are corbelled in this way it requires plaster or wooden cornices, as shown by the dotted lines, to give a proper finish for the angles of the rooms; and for this reason corbelling is not usually done when not required by law.

Corbelling for floor joists should not be attempted with soft or poor bricks.

354. CARRYING UP BRICK WALLS EVENLY.—The walls of a building should be carried up evenly, no part being allowed to be carried up more than 3 feet above any other part, except where it is stopped by an opening. The building up of one part of a wall ahead of the adjacent parts tends to cause unequal settlements; and the joints in the higher parts setting before the rest is added, the brickwork which is laid last is apt to settle away from the other and to weaken the walls, besides marring their appearance. Whenever it

is necessary to carry one part of a wall higher than the rest of it the end of the higher part should be stepped or *racked* back, and not run up vertically, with only toothings left for connecting the remainder of the work.

355. BONDING OF BRICK WALLS AT ANGLES.—An important detail in the construction of brick buildings is the secure bonding of the front and rear walls to the side or partition walls. When practicable, both walls should be carried up together, so that each course of bricks in both walls may be well bonded together. If, in order to avoid delay, the side walls must be built up ahead of the front wall, the ends of the side walls should be built with toothings, as shown in Fig. 205, eight or nine courses high, into

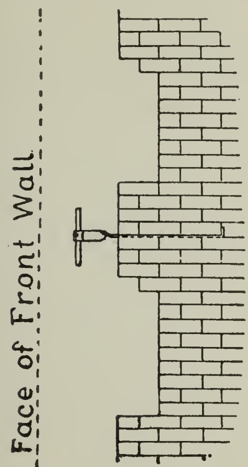


Fig. 205.—Toothing and Anchoring of Side Brick Walls.

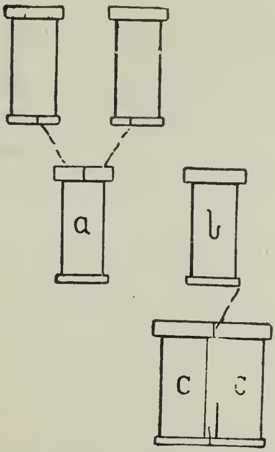


Fig. 206.—Cracks in Brick Walls Caused by Piers and Openings.

which the backing of the front wall should be bonded. In addition to the brick bonding, anchors made of ⅜ by 2-inch wrought-iron, with one end turned up 2 inches and the other welded around a ⅝-inch round bar, should be built into the side walls about every 5 feet in height, as shown in the figure. The anchors should be of such lengths that the rods will be at least 8 inches in from the back of the front wall and extend at least 17 inches into the side walls. The building regulations of most of the larger cities require that all intersecting brick walls shall be tied together in this way.

356. OPENINGS IN BRICK WALLS.—The locations of all door and window openings in brick walls should be carefully con-

sidered, not only as regards convenience, but also as to their effect on the strength of the walls. The combined widths of the openings in any bearing wall should not much exceed one-fourth of the length of that wall; and as far as possible the openings in the different stories should be over each other. The placing of a window either under a pier or directly over a narrow mullion, as at *a* or *b*, Fig. 206, should be especially avoided. If windows must be used in these positions, steel beams should be placed over the windows *a* and *c*, as a stone lintel or a brick arch would be quite sure to crack from the combined effects of the load and the settlement of the joints in the brickwork on either side of the windows.

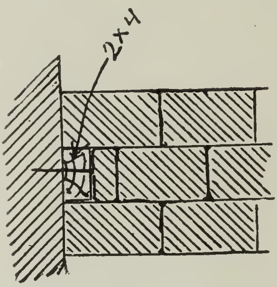


Fig. 207.—Simple Method of Joining New to Old Brick Walls.

All openings in exterior walls should have either relieving-arches or cast-iron or steel beams behind the stone caps or face-arches. Ordinary relieving-arches (see Article 372) are commonly used where the widths of the openings are less than 6 feet, and steel beams where the widths are greater. In bearing walls, where the tops of the openings come within 12 inches of the bottoms of the floor joists, it is hardly safe to use relieving-arches, unless the floor loads are very light.

For door openings in unplastered brick partitions, cast-iron lintels may be used to good advantage, as they give smooth, level soffits to the openings and show only narrow strips of metal on the faces of the walls.

357. JOINING NEW TO OLD BRICK WALLS.—When a new wall is to be joined to an old one, at right-angles, a groove should be cut in the old wall similar to that shown in Fig. 159 for the new wall to fit into and for the purpose of allowing it to settle independently. A cheaper method, and one more commonly used in light work, is to nail a scantling, a 2-inch by 4-inch piece of timber, to the wall of the old building, so that it will come in the middle of the new wall, as shown in Fig. 207. A similar method can be used for joining the ends of old and new walls. New work should never be toothed to old work unless the former is laid in cement.

358. THICKNESSES OF BRICK WALLS.—There is no practical rule by which it is possible to calculate the necessary thickness

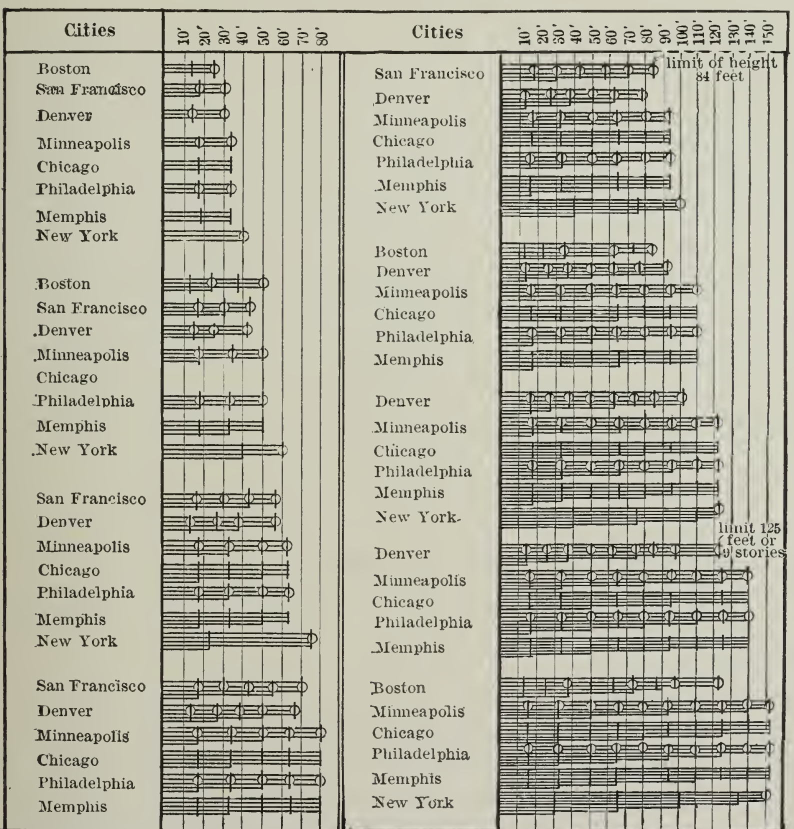
of a brick wall, as the resistance to crushing, which is the only direct stress, is usually only a minor consideration.

We must therefore rely principally upon experience in determining the thicknesses of walls for any given building, unless the construction of the building is controlled by municipal or State regulations.

In nearly all of the larger cities of the country the minimum thicknesses of the walls are prescribed by law or ordinance; and as these requirements are generally ample they are usually adhered to by architects when designing brick buildings.

TABLE XXVI.*

THICKNESSES OF WALLS OF MERCANTILE BUILDINGS IN VARIOUS CITIES, SHOWN GRAPHICALLY.



* Table XXVI and other matter of this chapter was prepared by Mr. Julian Millard. See also Tables X and Y in Appendix.

TABLE XXVII.

Maximum Story-heights for Thicknesses in Table XXVI.

Cities	Maximum story-heights in feet				Limits of lengths in feet	
	1st	2d	Intermediate	Top	More than	Less than
New York	...	...	...	...	40	105
Philadelphia	18*	15*	14*	...	75	125
Chicago	...	...	...	...	100	...
San Francisco	...	...	...	...	40†	...
Denver	14	...	12	16	40	125
Minneapolis	18*	15*	14*	...	...	100

* In the clear.
† Applies to walls over 60 feet high.

Table XXVI shows graphically the thicknesses of walls of warehouses and mercantile buildings in eight representative American cities. In this table each vertical subdivision represents ten feet of wall height and each horizontal line represents a half-brick (4 or 4½ inches) of wall thickness. Thus, three lines represent a 12 or 13-inch wall. The short cross lines show story-heights. If the law limits heights of stories, such limits are indicated by the small circles.

Table XXVII shows the maximum story-heights in feet for which the thicknesses in Table XXVI apply; and the minimum and maximum lengths (not heights) in feet within which the thicknesses of Table XXVI apply. The columns marked "limits of lengths" refer to lengths unsupported by buttresses or cross-walls.

Many ordinances require that in computing the thickness of exterior walls, facings in "running bond" shall not be included.

Although there is some difference in the thicknesses of walls given in the tables, a general rule might be deduced from the table, for mercantile buildings over four stories in height, which would be somewhat as follows:

For bricks equal to those used in Boston or Chicago, make the *thickness of the walls of the three upper stories* 16 *inches;* of the next three below, 20 inches; of the next three, 24 inches; and the next three, 28 inches. For a poorer quality of material, make the walls of the *two* upper stories only, 16 inches thick; those of the next three, 20 inches; and so on down.

In buildings less than five stories in height the top story may be 12 inches in thickness.

For the walls of dwellings, 13 inches and 9 inches may be used for two-story buildings; for three-story buildings the walls should be 13 inches thick the entire height above the basement; and for four-story buildings 17 inches in the first story and 13 inches for the entire height above.

In determining the thickness of walls the following five general principles should be recognized:

First. Walls of warehouses and mercantile buildings should be heavier than those used for living or office purposes.

Second. Clear spans exceeding 25 feet and unusually high stories require thicker walls.

Third. Great length is a source of weakness in a wall, and its thickness should be increased 4 inches for every 25 feet over about 100 feet in length.

Fourth. Walls containing over 33 per cent of openings should be increased in thickness.

Fifth. Partition walls, if not over 60 feet long, may be 4 inches less in thickness than the outside walls, but no partition should be less than 8 inches thick.

359. BRICK PARTY-WALLS.—There is much diversity in building regulations regarding the thickness of party-walls, although they all agree that such walls should never be less than 12 inches thick. About one-half of the laws require the party-walls to be of the same thickness as exterior walls; the remainder are about equally divided between making the party-walls 4 inches thicker or 4 inches thinner than if they were independent side walls.

When the walls are proportioned by the rule previously given, the author believes that the thickness of the party-walls should be increased 4 inches in each story. The floor load on a party-wall is obviously twice that on the side walls, and the necessity for thorough fire-protection is greater in the case of party-walls than in that of other walls.

360. BRICK CURTAIN-WALLS.—In buildings of the skeleton type the outer masonry walls are usually supported either in every story or every other story by the steel framework, and carry nothing but their own weight. Such walls may, therefore, be considered as only one or two stories high, and are often made only

12 inches thick for the whole height of a twelve or fifteen-story building unless building laws require a greater thickness.

361. WOOD IN BRICK WALLS.—As a rule, no more woodwork should be placed in brick walls than is absolutely necessary. Wooden lintels for supporting brick walls are objectionable not only on account of their non-resistance to fire, but also on account of their tendency to shrink. It is generally impossible to obtain framing lumber that is thoroughly dry, and when a brick wall is partially supported by a wooden lintel a crack is quite sure to develop sooner or later in the manner shown in Fig. 208. The crack is obviously caused by the shrinkage of the lintel, which permits the portion of the wall supported on it to settle by an amount equal to the shrinkage of the wood. The portion of the wall *a*, being supported on the brick pier, does not settle.

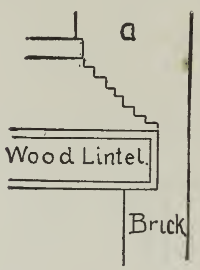


Fig. 208.—Cracks in Brick Wall Caused by Shrinkage of Wood Lintel.

Bond-timbers, or pieces of studding laid under the ends of the floor joists, are also objectionable, because they are quite sure to shrink, leaving the walls above them unsupported. Bond-timbers are very convenient for the carpenters, as they give a level bearing for the floor joists, and distribute the weight over the brickwork; but they should never be used in buildings which are over two stories in height, nor in walls which are less than 12 inches thick. If used at all, they should be selected from the driest lumber that can be obtained.

For the proper use of wooden lintels under relieving-arches see Article 372.

Strips of wood are sometimes built into walls to form a nailing for the wood finish or for the furring strips. Such strips should not be used in buildings over two stories in height, and should not be over ⅜ of an inch thick, so that they may take the place of the mortar joints.

Wooden bricks also, or blocks of wood of the size of bricks, are sometimes built into brick walls to provide nailings for furring strips, door frames, etc. These not only tend to weaken the walls, but they also generally shrink enough to become loose, thereby losing their holding power.

Plugs.—It is a common practice to drill holes in the brickwork and to drive in wood plugs for the nailings. While these plugs are

generally efficient, they cannot be depended upon, as they are often loosened by the shrinkage or split by the nails.

In first-class work nailings should be provided as the walls are built by porous terra-cotta blocks or by the Rutty metal wall-plugs, shown in Fig. 209. The porous terra-cotta will hold nails

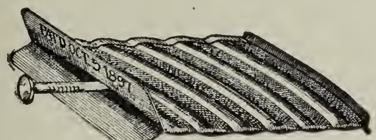


Fig. 209.—The Rutty Steel Wall-plug.

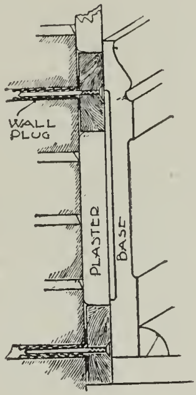


Fig. 210.—The Rutty Steel Wall-plug. Face Flush with Masonry.

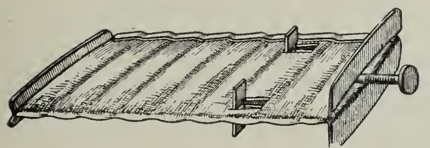


Fig. 211.—The Rutty Non-furring Wall-plug.

almost as well as timber will, but greater dependence can be placed upon the metal plugs than upon either of the others. These wall-plugs are made of steel, thoroughly japanned, and may be obtained in either of two forms. One type is intended to be set in the joints with the edges flush with the masonry, as in Fig. 210. The others, called "non-furring plugs," Fig. 211, are set with their faces ¾ of an inch out from the masonry, as in Fig. 212. Wood furring-strips or metal-lath may be nailed directly to these, and thus be entirely insulated from the walls.

362. CRACKS IN BRICK WALLS.—It is a very common thing to see cracks in brick walls. These cracks may be produced by any one of several causes.

Probably the most frequent cause of the cracking of masonry walls is the settlement of the foundations, due either to their improper design or to a settlement of the ground caused by excessive moisture. A strict observance of the rules laid down in Articles 25, 32 and 33 will generally prevent cracks due to faulty foundations.

The effect produced on certain soils by a saturation with water is described in Article 9.

Next to faulty foundations, probably the commonest cause of cracks in brick walls is the use of wooden lintels, as described in Article 261.

Besides the cracks resulting from these causes are those which often appear over openings, and which are due to the settlement of the mortar joints in the piers or to the spreading of arches.

Small cracks are commonly seen just above the ends of door sills or window sills, as shown in Fig. 213. Such cracks generally appear near the bottoms of high walls, and are caused by the compression of the mortar in the lower joints of the piers. They may be avoided by using slip-sills, as described in Article 282, but are not likely to occur when cement mortar is used.

Another place where cracks produced by the settlement of mortar joints sometimes occur is where a low wall joins a very high one.

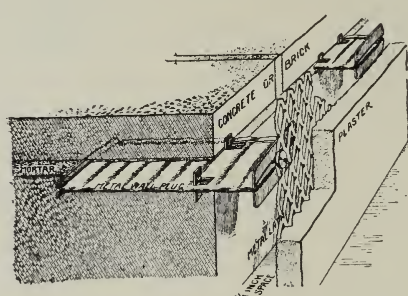


Fig. 212.—The Rutty Non-furring Wall-plug.

Fig. 213.—Cracks Over Sills Caused by Joint Compression.

To prevent such cracks the walls should be joined by a slip-joint, as described in Articles 315 and 357.

Cracks are generally more likely to occur in walls that are broken by frequent openings than in those that are plain and unbroken.

The use of plenty of anchors and thorough bonding does much toward preventing cracks.

363. DAMP-PROOF COURSES.—When buildings are built on ground that is continually moist or wet, the moisture is very apt to soak up into the walls from the foundations, rendering the building unhealthy and often causing the woodwork to rot. To prevent the moisture rising in this way a horizontal damp-proof course should be inserted in all walls below the level of the first floor

joists. It should be at least 6 inches above the highest level of the soil touching any part of the outer walls, and should run unbroken all around them and at least 2 feet into all the cross walls; and on very wet ground, where the water is but a few feet below the surface, it should be continuous through all the walls. In buildings finished with parapet walls it is also desirable to insert a damp-proof course just above the flashings of the roofs or gutters to prevent the moisture from soaking down into the woodwork of the roof and into the walls below.

Materials.—These damp-proof courses may be formed of any one of several materials:

Asphalt.—A layer of rock asphalt ⅜ of an inch thick makes an excellent damp-proof course. The surface to receive the hot asphalt should be quite dry and should be made smooth to economize material, and all the joints should be well flushed up with mortar. The best asphalts for this purpose are the natural rock-asphalt from Seyssel, Val de Travers or Ragusa, which are imported into this country in the shape of blocks and cakes. When used the cakes are melted in large kettles, and mixed with a small proportion of coal-tar and applied hot. One or two layers of tarred felt also, imbedded in the hot asphalt, may be used with good results.

"*Roofing slates*, or even hard *vitrified bricks*, two courses breaking joint, laid in half cement and sand mortar, or such bricks laid without any mortar in the vertical joints, form an inexpensive damp course." *Glass* also has sometimes been used for this purpose.

Portland Cement.—A ½-inch layer of Portland cement mortar, mixed in the proportion of 1 part of cement and 1 of sand, will often answer the purpose, but is not as desirable as the materials mentioned above.

There are many other special preparations used for this purpose.

364. HOLLOW BRICK WALLS. THEIR OBJECT.—It is well known that solid brick walls readily absorb moisture and transmit heat and cold. A driving rainstorm will often penetrate 12-inch brick walls so as to dampen the wall-paper or soil the fresco decorations.* It is also known that a house with damp walls is unhealthy and a frequent cause of rheumatism; besides this, the moisture in

* So-called solid brick walls are by no means really solid, and facings, apparently tight, have frequent holes through which water will gain admittance. There is, therefore, nothing mysterious in the above statement. But if the walls are made so solid and dense that they are impervious to water, their conductivity is high, and the warm air of the interior rapidly deposits its moisture and dirt upon the walls. Such conditions are even more unsanitary than conditions resulting in moisture from the outside.

the brickwork prevents the mortar, if made of lime, from becoming hard, and is also liable to communicate itself to the woodwork, thereby causing rot.

A building with damp walls will also require the consumption of very much more coal to warm it than one with dry walls, as the moisture must be evaporated before the temperature of the walls can be raised.

To overcome these objections to solid brick walls, particularly in residences and school-houses, hollow or vaulted walls have been used, and earnestly recommended by various persons.

Theoretically, a hollow wall should prevent the passage of moisture through it, or insulate the interior from the exterior surfaces, and by providing air-spaces in the walls, make the building much cooler in summer and warmer in winter.

In the actual construction of the walls, however, certain difficulties are met with, which, to a considerable extent, offset the advantages; so that hollow walls are comparatively little used in this country.

The author believes, however, that their use might be much extended with beneficial results, especially for isolated buildings.

To obtain the full benefit of the air-spaces they should be continuous throughout the walls, and the bonds or connections between the two parts should be of such material and of such shape that the moisture which penetrates the outer portions cannot be conveyed across to the inner portions.

To provide continuous air-spaces in walls penetrated by openings is practically impossible, although it may be quite closely approximated.

The objections commonly urged against vaulted walls are increased cost and increased ground area, the latter being an important consideration in city buildings.

365. METHODS OF HOLLOW-WALL CONSTRUCTION.—There are several ways of constructing hollow or vaulted walls. They differ principally in the method of bonding and in the thickness of the inner and the outer portions of the walls.

Generally, at least one portion of the wall must be made 8 inches thick to sustain the weight of the floors, the other portion being only 4 inches thick. The thicker portion is more commonly placed on the outside of the walls; but this necessitates extending the floor joists across the air-space, thus to a great extent neutralizing the benefits expected to be derived from it. By this method the thicker

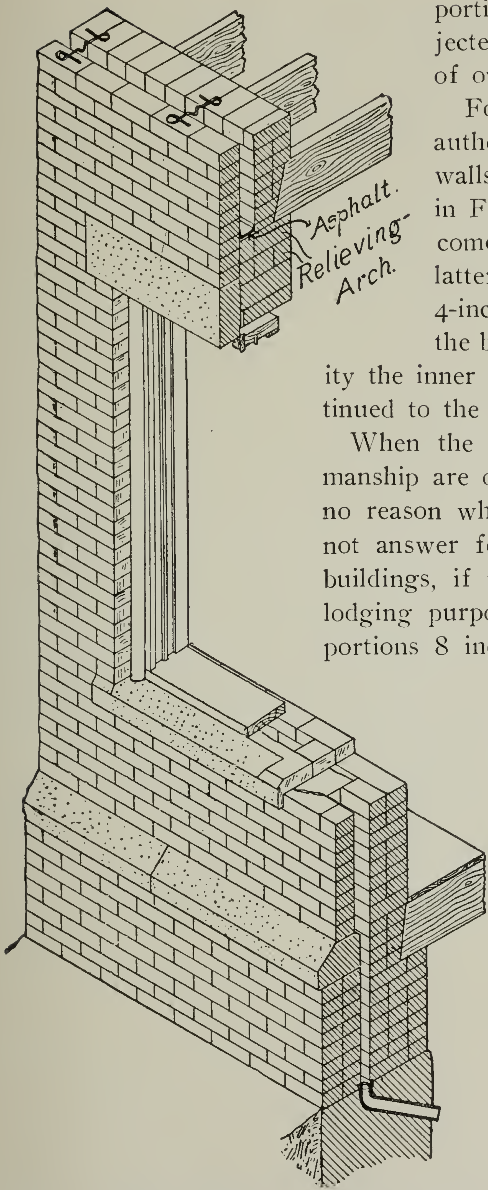


Fig. 214.—Brick Hollow-wall Construction for Two-story Buildings.

portion of the wall is still subjected to the injurious effects of outside moisture.

For two-story buildings the author recommends that the walls be constructed as shown in Fig. 214. If the wall-plates come above the attic joists the latter may be supported on two 4-inch walls if well built. If the bricks are not of good quality the inner 8-inch wall should be continued to the upper joists.

When the bricks, mortar and workmanship are of the best quality there is no reason why this construction should not answer for even four or five-story buildings, if used only for dwelling or lodging purposes, by making the inner portions 8 inches thick the full height, and by increasing the width of the air-spaces to 6 inches.

For warehouses the bearing wall in the lower stories should be increased in thickness.

A hollow wall of a given number of bricks, securely bonded, is much more stable than a solid wall of the same number of bricks, and will also withstand fire better. It requires much better workmanship, however, than is generally bestowed on solid walls,*

* A 4-inch brick wall is more likely than a thicker wall to be solid and to have well-filled joints.

and the mortar, particularly in the outer portions, must be of the best quality, and preferably of cement.

The outer and inner walls should be built of the same kind of mortar and at the same time, to avoid unequal settlement. For country and suburban houses the following, shown in Fig. 215, gives a reasonably good hollow-wall construction at small expense: The foundation walls are made solid to the bottoms of the first-story joists. Upon these are built two 4-inch walls, 2 inches apart, bonded across with wire bonds. The walls are made solid for two or three courses below the second-floor joists, and thence continued as hollow walls to the second course below the ceiling. From this level they are made solid up to plates, reducing to 8 inches in thickness back of the cornice. The corners are made solid, and 4-inch solid withes are built at the jambs of openings. The heads are made solid. A wire bond is used in every square foot of wall surface. A few holes left through the solid parts, giving air circulation from cellar to attic, will tend to quickly evaporate any moisture before it passes in any perceptible quantity from the outside to the inside.

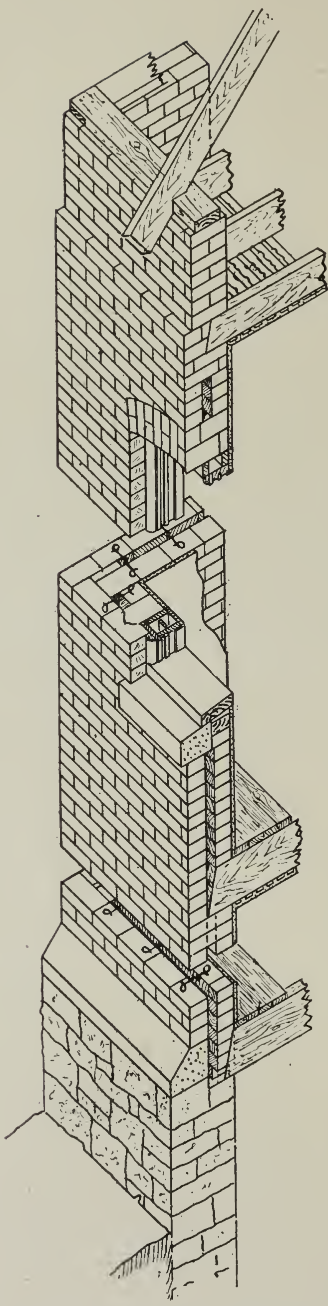


Fig. 215.—Brick Hollow Walls for Cheap Cottage Construction.

Cement mortar or lime-and-cement mortar should be used, although in dry climates lime mortar is used with success. This construction is very stable when used in houses not over two stories in height. It requires neither furring nor lath, and usually is no more expensive than solid walls, furred and lathed. It is especially recom-

mended for houses that are to be plastered on the outside. At prevailing prices (1907) it costs but little more than wood construction and less than brick-cased or veneered construction.

Facing-brick may be used on the outside if both parts are laid in cement mortar.

Nearly all building regulations require that at least the same quantity of bricks shall be used in the construction of hollow walls as would be used if the walls were built solid; and many of them require that both portions of the walls shall be at least 8 inches thick, if they are used as bearing walls.

For heavy buildings, with steel floor joists and girders, it is better to build the outer walls the full thickness that would be required in the case of single walls, and to make the inner walls only 4 inches thick, to serve merely as a furring and to receive the plaster. Where fire-proof arches are used for the floors, these inner walls might without injury rest on the floor arches.

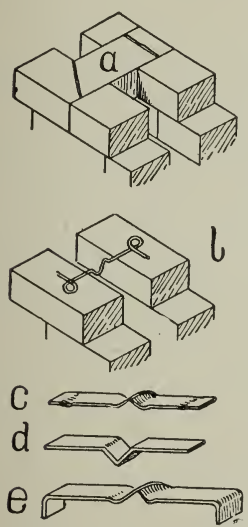


Fig. 216.—Bonds and Ties for Brick Hollow Walls.

366. BONDING OF HOLLOW WALLS.—To secure proper strength in these walls it is necessary that the two portions shall be well bonded together, so that neither will buckle nor get out of plumb. Until within a few years this bonding was usually accomplished by placing brick headers across the air-spaces with the ends built a short distance into the two portions of the walls, as shown at *a*, Fig. 216.

Brick bonding, however, neutralizes much of the benefit gained by an air-space, as it permits the passage of moisture through walls wherever they are bonded. The moisture not only passes through the bond bricks, but also through the mortar droppings that invariably collect upon them.

The best method of bonding, and the only one which retains the full benefits of an air-space, is the one using metal ties provided with a drip in the middle. Any one of the metal ties shown in Fig. 216 may be used. That shown at *b* is the "Morse" tie, which is made of different sizes of galvanized-steel wire and which varies from 7

to 16 inches in length. The other ties are not patented, and may be made by any blacksmith.

The one shown at *e* is probably the best shape where both walls are 8 inches thick, as it takes a firm hold on the walls and is also much stiffer than the wire ties. The iron ties should be either galvanized or dipped in hot asphalt or coal-tar.

Wire ties are probably best for 2-inch air-spaces, as they stop no mortar droppings and accommodate themselves to slight settlements without injury to either wall. In wider spacings greater stiffness is advisable and plate-iron ties should be used, although the same result might be attained by using wire ties at more frequent intervals.

Galvanized wire and sheet-metal ties are manufactured in great variety for use in solid walls, hollow walls and brick-cased or veneered walls. It should be noted that in hollow walls mortar droppings will pile up on any ties which present horizontal flat surfaces.

If ties of any of the shapes shown at *b*, *c* or *d* are used they should be spaced every 24 inches in every *fourth* course. The tie *e*, being stronger, need be used in every *eighth* course only.

367. CONSTRUCTION AROUND OPENINGS IN HOLLOW WALLS.—Wherever door or window openings occur in hollow walls it is necessary to build the walls solid for 8 inches at each side of the openings, and also to carry the relieving-arches entirely through the walls. It is almost impossible to prevent some moisture from passing through the walls at these points; but much may be done by covering the tops of the relieving-arches with hot tar and laying the connecting brickwork in cement mortar. The tops of the relieving-arches are obviously the most vulnerable points, and should be protected in some way and kept as free as possible from mortar droppings.

368. VENTILATION OF AIR-SPACES IN HOLLOW WALLS.—There seems to be some difference of opinion as to whether or not the air-spaces should be connected with the outer air. American writers, however, appear to be generally of the opinion that the air-spaces should be ventilated to carry off the moisture that collects on the inside of the outer portion of the walls.

It is recommended that the bottoms of the air-spaces be ventilated through openings into the cellar, and that openings be left in the inner portions of the walls just under the copings of parapet

walls, or above the attic floor joists if the walls are covered by the roof. If the air-spaces cannot be ventilated into the attic, then ventilation flues should be carried up and topped out like chimneys, or built in connection with chimneys. It is also recommended that U-shaped drain tile be laid at the bottoms of the air-spaces to collect any moisture that may run down the outer walls.

369. HOLLOW BRICK WALLS WITH BRICK WITHES. —Brick walls are sometimes built with 4-inch inner and outer

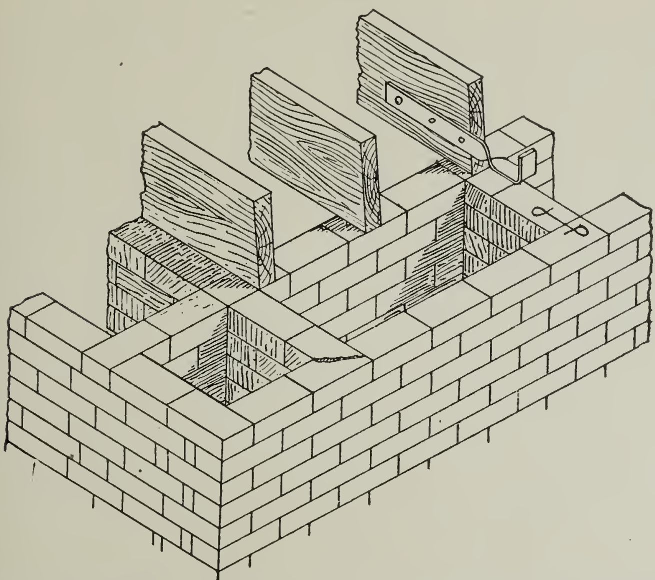


Fig. 217.—Brick Hollow-wall Construction. Congress Hall, Saratoga, N. Y.

facings connected with *solid* brick withes, as shown in Fig. 217, the air-spaces being made 4, 8 or 12 inches, according to the height and character of the buildings. Congress Hall, Saratoga, N. Y., a portion of which is seven stories high, was built in the manner shown in Fig. 217, and stood successfully. If such walls are built with the best kind of common bricks, and if the workmanship is *perfect*, they should have ample strength for any ordinary three or four-story building, and would certainly be more stable and conduct less heat and moisture out of and into the building than in the case of solid walls containing one-half more bricks. With such poor bricks and workmanship as are commonly found in many parts of this country, however, walls built in this way should never be used

for any building larger than an ordinary two-story dwelling. Theoretically, the insides of the walls opposite the withes would be subject to dampness, but of course not to so great an extent as in the solid walls.

For two-story dwellings these walls, if well constructed, and if the withes are securely bonded to the facings, should make much healthier and more comfortable buildings than those built with solid walls.

There are several forms of plaster-blocks and plaster or stucco-boards which may be applied with excellent results to the inside of brick walls, to form air-spaces. As plaster of Paris is very absorbent, care must be taken to prevent any contact with the brickwork. The Rutty metal non-furring plugs may be set where wanted in the joints when the bricks are laid. The faces of these plugs stand ¾ of an inch from the brickwork. Plaster blocks may be tied to nails driven into these plugs, and for plaster-board, strips may be nailed to the plugs for a nailing. Either method is a great advance over ordinary wood furrings and laths.

370. FURRING-BLOCKS FOR BRICK WALLS.—For office buildings furring-blocks designed for that especial purpose are often used for lining or furring the external walls, and sometimes hollow bricks are used for the inner 4 inches of solid walls; but the latter have not proved a success in excluding moisture. The objection to any kind of furring and to hollow bricks is that there must necessarily be some connection between the *material* of the lining or furring and the walls themselves, and this connection allows the passage of heat and moisture.

371. BRICK-VENEER CONSTRUCTION.—It is quite common in many sections of the country to build dwellings, and even three and four-story buildings, with outer walls of frame construction veneered with 4-inch facings of brick. Buildings built in this way have the same appearance, both outside and inside, as if the walls were built entirely of brick.

Where lumber is cheap and brickwork comparatively dear, this method of construction possesses some advantages, although it is not generally approved by architects; and it should be used only where hollow brick walls cannot be afforded. The advantages possessed by brick-veneered frame walls over solid brick walls are the lower cost, and the air-spaces, which latter prevent any pos-

sibility of the passage of moisture, and also make the houses much warmer in winter and cooler in summer.

About the only advantage that it possesses over a method resulting in well-built frame buildings is that it reduces the insurance rate, as the veneer offers some protection from fires starting in adjoining buildings. Veneered buildings, however, are not nearly as free from danger from fire as brick buildings are, and they would probably be destroyed by fire on the inside about as rapidly as though the frame were covered with siding or shingles.

The only differences in the planning of a veneered building from that of a frame building are that in the former the walls are about

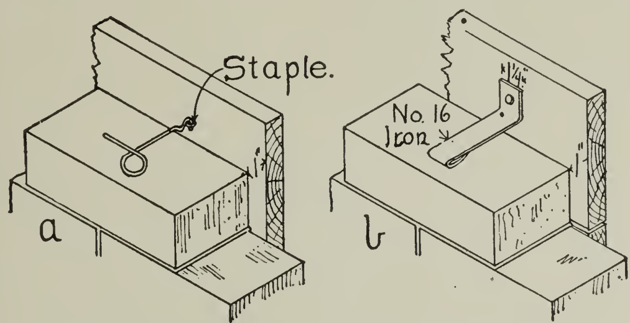


Fig. 218.—Brick-veneer Construction. Metal Ties.

5 inches thicker and the foundations project sufficiently beyond the frame to support the veneer. The elevations are drawn the same as for a building with solid brick walls.

The wooden frame should be constructed in the best manner, with at least 4 by 6-inch sills, 4 by 8-inch posts, 4 by 6-inch girts and 4 by 4-inch plates, and should be well braced at the angles. After the frame is up it should be sheathed diagonally and then covered with tarred felt.

It is also very important that the framing timber should be as dry as possible, and particularly so for the sills and girts. The frame must also be perfectly plumb and straight.

The veneer is usually laid with pressed or face-bricks, with plumb bond, which should be tied to the wooden walls with metal ties. Ties similar to the Morse ties, shown at *a*, Fig. 218, are probably the best for this purpose, although the author has used ties of the form shown at *b* with very satisfactory results. The ties should be placed on every other brick in every fifth course.

In laying out the walls on the floor plans 6 inches should be allowed from the outside of the studding to the outside face of the brick walls. This gives an air-space of about 1 inch between the bricks and sheathing and avoids chipping the bricks where the wooden walls are a little full. It is a good idea to build 2-inch U-shaped drain tiles in the foundation walls under the air-spaces to collect any moisture that may penetrate the veneer. The air-spaces should also be ventilated at the bottom through 2-inch drain tiles, as shown in Fig. 219.

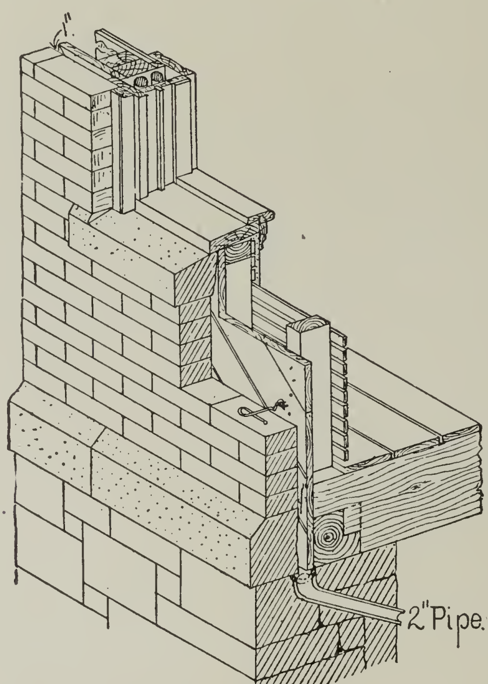


Fig. 219.—Common Type of Brick-veneered Construction.

The top of the brickwork generally terminates under the eaves or gable finish. If the building has a flat roof, with parapet walls, the latter should be coped with either copper or galvanized-iron and tinned on the back down to the flashing.

Fig. 219 shows a partial section through the foundation and a portion of the first-story wall of a veneered dwelling to illustrate the construction described above.

Fig. 220 shows a section through a brick-veneered wall, with

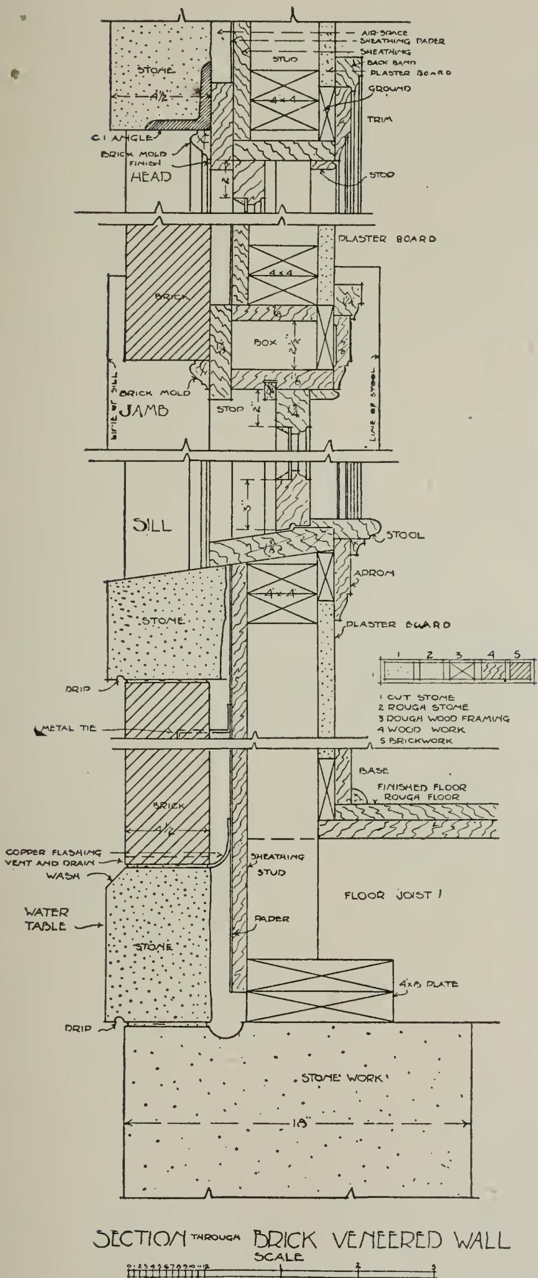


Fig. 220.—Sections Through Brick-veneered Wall.

some variations in details of construction from those shown in the preceding figures; and the following is a brief description of the construction shown and a mention of the claims made for it by its advocates in the Middle West districts of the country. Stone veneer as compared with brick veneer is also mentioned.

In the Middle West both brick and stone veneer construction is now (1908) regularly used, especially in the first story. This story, up to the tops of the first-story windows, is veneered with brickwork or with rough field-stones. The second story is covered with siding or shingles. The cost of such veneered houses, at the present time, is very little higher in these districts than that of houses built with solid brick walls. As shown in this section, the walls are generally 10½ or 11

inches thick, allowing 4½ inches for the brick veneer, 1 inch for the air-space and paper, $\frac{13}{16}$ of an inch for the sheathing, 3⅝ inches for the studs and $\frac{13}{16}$ of an inch for the plaster-board, sheathing-lath or lath and plaster.

Any water absorbed by the brickwork runs down the inside face to the copper flashing, out through occasional holes cut in the lower bricks, down the face of the water-table and to the ground from the drip. Bricks similarly perforated and placed at the top of the wall act as ventilators for the air-space.

The veneer is tied to the sheathing by metal ties tacked to the latter and imbedded in the mortar joints.

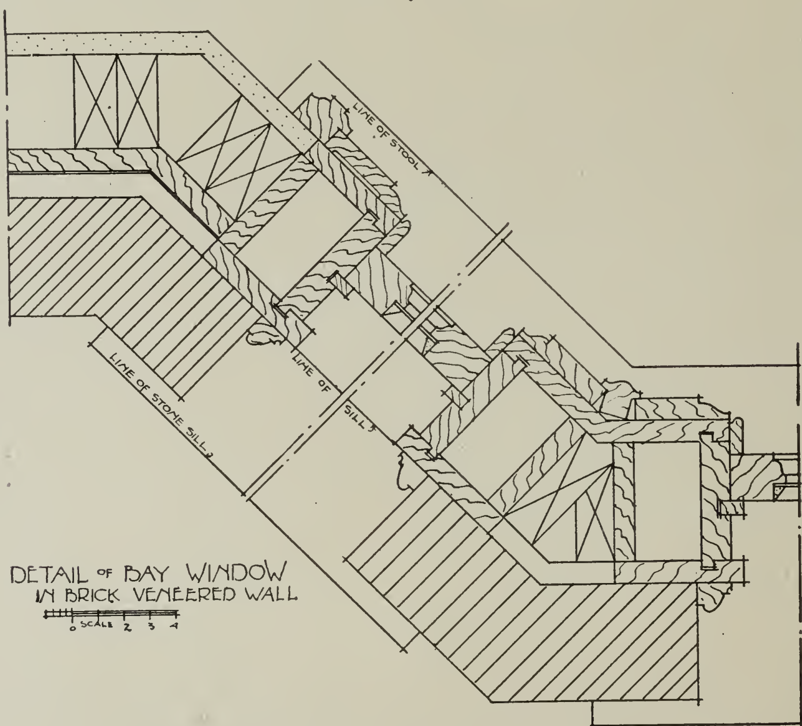


Fig. 221.—Detail of Bay-window in Brick-veneered Wall.

In order to imitate special brick bonds, half bricks are sometimes used to represent headers.

When the stone veneer is used there is a variation of the construction to effect the bonding of the stonework. When rough field-stones are employed long bond-stones are run in between the studs occasionally, and plaster-board or sheathing-lath substituted

for the sheathing, and put on the inside of the studs. Metal ties are used in this construction also.

Fig. 221 shows the details of a bay-window in a brick-veneered wall. The mullions are of brick, and the window frames made for double-hung sash. The bricks for the mullion angles are ground rather than clipped. In this construction there is ample room for the weight-boxes.

Fig. 222 shows the details of a wooden bay in a brick wall, the

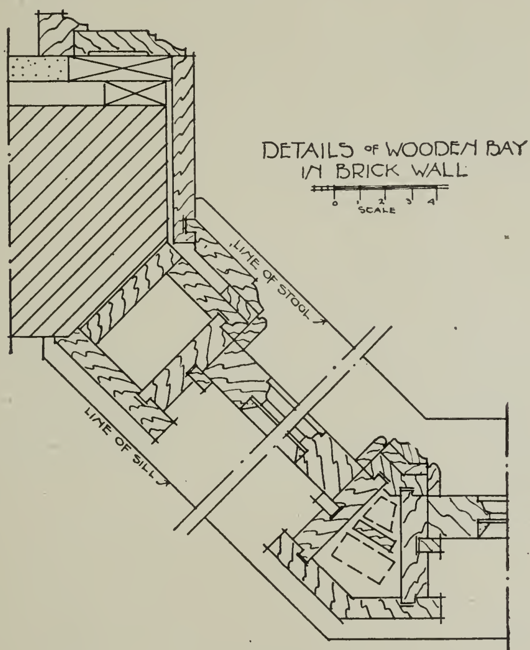


Fig. 222.—Detail of Wooden Bay in Brick Wall.

wall being in this illustration solid. Whether the walls are solid or veneered, there is often difficulty met with in getting room enough for the weights in the boxes when the bay mullions are of wood; and either the widths of the mullions have to be increased or special-shaped weights of greater lengths used. With casement window sash or brick mullions these difficulties disappear.

4. MISCELLANEOUS DETAILS IN BRICKWORK.

372. BRICK ARCHES.*—Brick arches are generally used for

* For a discussion of the stability of arches, reference may be made to the "Architect's and Builder's Pocket-Book." Frank E. Kidder.

spanning the openings in brick walls, and where there is sufficient height for an arch it forms the most durable support for a wall above. The arches should be laid with great care and with full joints, and all having a span of over 10 feet should be laid in strong cement mortar. It is indeed much safer to lay all brick arches in cement mortar.

Gauged Arches.—When arches are built of common bricks the latter are laid close together on the inner edge, with wedge-shaped joints, as shown in Fig. 229; but when built of face-bricks the arch rim is laid out on a floor and each brick is cut and rubbed to fit exactly the place chosen for it, so that the radial joints are of the same thickness throughout. Such work is called "gauged work."

Bond in Brick Arches.—The only detail requiring especial mention in connection with brick arches is the bond. When gauged

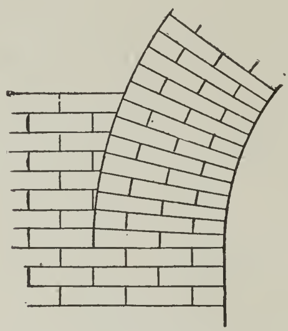


Fig. 223.—Bonded Gauged Brick Arch.

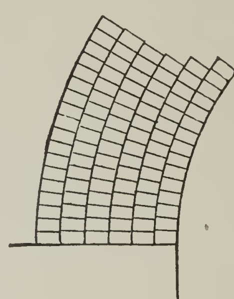


Fig. 224.—Rowlock Brick Arch.

arches are used the bricks are generally bonded on the face of the arch to correspond with the face of the wall, as shown in Fig. 223. Such an arch is called a "bonded arch." Bonded gauged work makes the neatest and strongest work, but it is too expensive to be used in common brick arches.

Arches of common bricks are generally built in concentric rings, either constructed so that they have no connection with each other, except that resulting from the tenacity of the mortar, or else bonded every few feet with bonding courses built in at intervals like voussoirs, as shown by the heavy lines at *A,* Fig. 225. When the concentric rings are all headers, as in Fig. 224, the arch is designated a "rowlock arch," and the bond "rowlock bond"; and when the arch is built with bonding courses, as in Fig. 225, the bond is known as "block-in-course bond." Segmental arches are often built with con-

centric rings of stretchers (Fig. 226), which may be bonded at right-angles to the face of the arch by hoop-iron. When the radius is over 15 feet this latter construction should be stronger than the rowlock bond.

Common brick arches are sometimes bonded by introducing headers so as to unite two half-brick rings wherever the joints of two

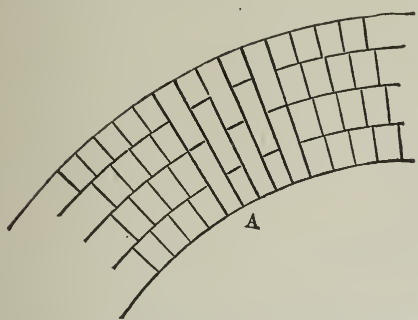


Fig. 225.—Brick Arch with Block-in-course Bond.

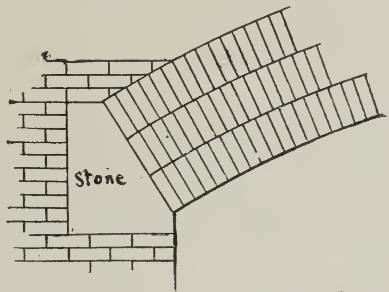


Fig. 226.—Arch with Concentric Rings of Stretchers.

such rings happen to coincide. Fig. 227 shows the bonding employed in arching the Vosburg tunnel on the Lehigh Valley Railroad, the span being 28 feet. The objection to building an arch in concentric rings is that each ring acts nearly or quite independently of the other, and the least settlement in the outer rings throws the entire pressure on the inner ring, which may not be able to resist it. When bonding courses are used, however, they serve to tie the rings together and to distribute the pressure between them, so that the above objection is overcome. For arches of wide span, or for those heavily loaded, some form of block-in-course bond should be used. Hoop-iron is often built into arch-rings parallel to the soffit, and is also often worked into the radial joints to unite the different rings. The stability of an arch may be greatly increased by its use.

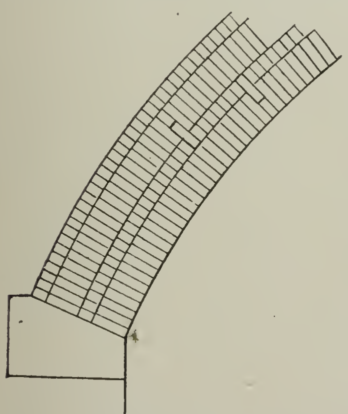


Fig. 227.—Brick Arch over Vosburg Tunnel, Lehigh Valley Railroad.

Skewbacks for Brick Arches.—In building brick arches of large span it is important to have solid bearings for the arches to spring

from. Such bearings may be best obtained by using stone skewbacks, as shown in Figs. 226 and 227. The stones should be cut so as to bond into the brickwork of the piers, and the springing surfaces should be cut to true planes, radiating from the center from which the arch is struck. The skewbacks should always be bedded in cement mortar.

Flat Arches of Brick.—Flat arches are often built over door or window openings in external walls for convenience or architectural effect. Such arches, if built with perfectly level soffits, almost always settle a little, and it is better to give a slight curve to the soffits, as in Fig. 228, or else to support the soffits of the arches on angle-bars, the vertical flanges of the bars being concealed behind the arch.

Brick Relieving-arches.—The portion of a wall back of a face-brick arch or stone lintel over a door or window opening should be

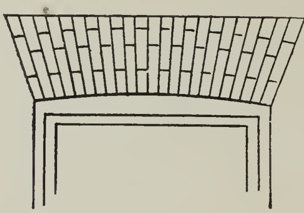


Fig. 228.—Brick Flat Arch with Curved Soffit.

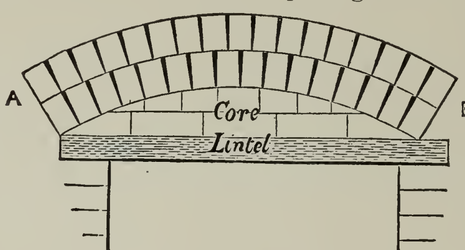


Fig. 229.—Brick Relieving-arch.

supported by a rough brick arch, as shown in Fig. 229. A wooden lintel is first put across the opening, and on this a brick core or center is built on which to turn the arch. Sometimes arched wooden lintels are used and the arch turned on them. In the case of plastered walls without furring, the method shown in the figure is the best, as there is less woodwork. The wood lintel should have a bearing on the wall of not more than 4 inches, and the arch should spring from beyond the end of the lintel, as at *A*, and *not* as at *B*, as in the latter method the arch is affected by the shrinkage of the lintel.

373. BRICK VAULTS.—Brick vaults are usually constructed in the same way as common brick arches, except that the bricks should be bonded lengthwise of the vault.

Cross vaults, or groined vaults, are generally supported at the intersections by diagonal arches of the proper curvature, built so as to drop from 8 or 12 inches below the soffits of the vaults.

Vaults may be economically constructed by a combination of brickwork and concrete, or even entirely of concrete. When built entirely of concrete, however, very strong centers are required.

Fig. 230* shows a method of constructing vaults much used by the ancient Romans. A light temporary center of wood was first put in place, and on this light brick arches were built to form a framework for supporting the weight of the vault until set. These brick arches were called "armatures," and as they became the real support of the vault only very light wooden centers were required.

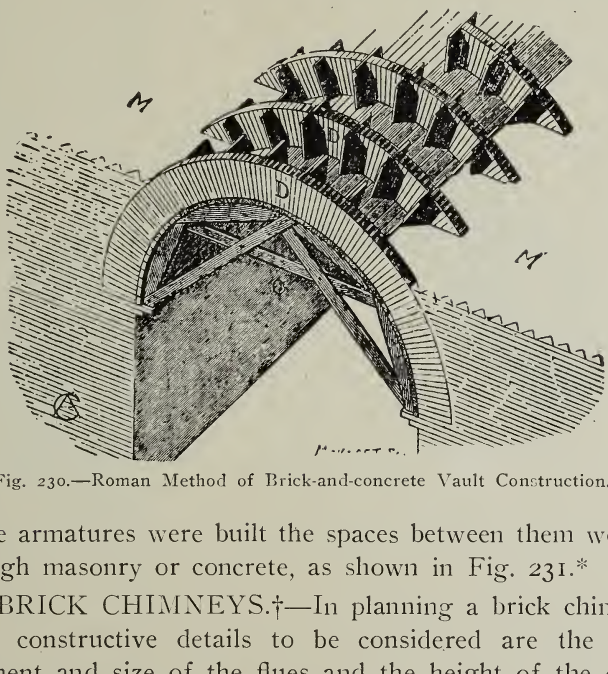


Fig. 230.—Roman Method of Brick-and-concrete Vault Construction.

After the armatures were built the spaces between them were filled with rough masonry or concrete, as shown in Fig. 231.*

374. BRICK CHIMNEYS.†—In planning a brick chimney the principal constructive details to be considered are the number, arrangement and size of the flues and the height of the chimney. Every fireplace should have a separate flue extending to the top of the chimney. Two or three stoves, however, may be connected with one flue if it is of sufficient size, and the kitchen range may be connected with the furnace-flue without bad results, and often the draught of the furnace will be benefited thereby. For ordinary stoves and for a small furnace an 8 by 8 inch or a 9 by 9 inch flue, depending upon the way the bricks are laid and bonded, is suffi-

* Figs. 230 and 231 are taken from *The Brickbuilder* by permission.
† Suitable sizes for flues for house heaters are given in tables in the "Architect's and Builder's Pocket-Book." Frank E. Kidder.

ciently large if built so that it is smooth on the inside; but it is generally better to make furnace-flues 8 by 12 inches or 9 by 13 inches and the fireplace-flues, also, the same size, except those for very small grates.

The best smoke-flue is one built of bricks and lined with fire-clay tiles, or else one made of a galvanized-iron pipe supported in the middle of a large brick flue. When the latter arrangement is used the space surrounding the smoke-pipe may be used for ventilating the adjoining rooms by simply putting registers in the walls of the flue.

When galvanized-iron smoke-pipes are used the metal should be

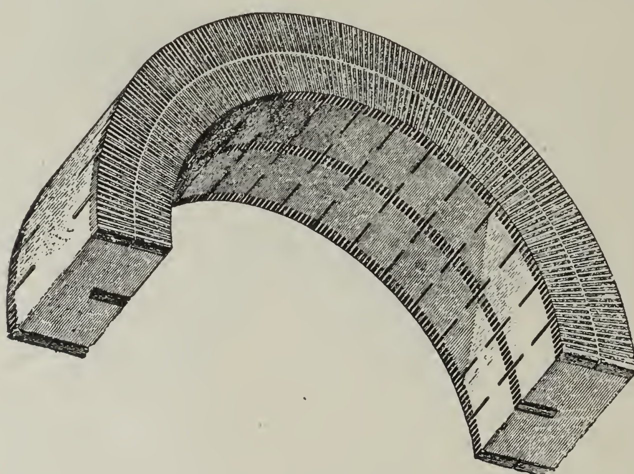


Fig. 231.—Roman Method of Brick-and-concrete Vault Construction.

at least No. 20 gauge, and No. 16 gauge for boiler-flues. Even then the pipes are liable to be eaten away by rust or acids within ten or twelve years. Fire-clay flue lining, on the other hand, is imperishable.

Smoke-flues are sometimes made only 4 inches wide. Such flues may work satisfactorily at first, but they soon get clogged with soot and fail to draw well, and should never be used unless it is impracticable to make the width greater.

Flues smoke or draw poorly oftener on account of the insufficient height of the chimney than from any other cause. A chimney should always extend a little above the highest point of a building or of buildings adjacent to it, as otherwise eddies formed by the wind may cause downward draughts in the flues, making them

smoke. If it is impracticable to carry a chimney above the highest point of a roof, it should be topped out with a hood, open on two sides, the sides parallel to the roof being closed. The walls and the *withes,* or partitions, of a chimney should be built with great care, the joints carefully filled with mortar and when there is no lining the joints should be struck and the inside surfaces made as smooth as possible.

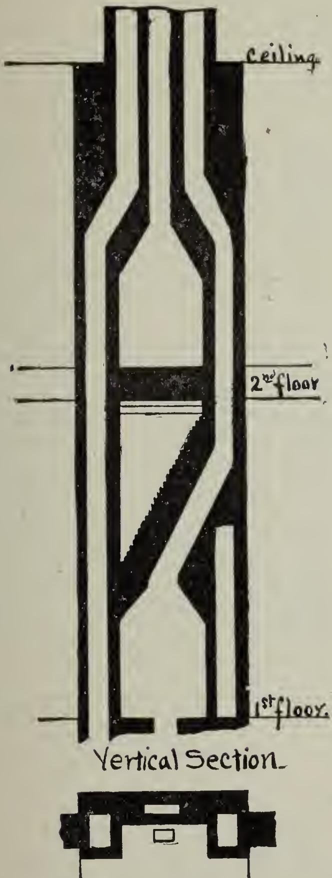


Fig. 232.—Brick Chimney Flues for Furnace and Fireplaces.

Specifications sometimes call for flues plastered smoothly on the inside with Portland cement, both to prevent sparks from passing through the walls and to increase the draught; and in England chimneys were formerly plastered with a mixture of cowdung and lime mortar, which was called "pargetting." Portland cement is not affected by heat and is the best material for this purpose.

Many building laws, however, forbid the plastering of the flue surfaces on account of the tendency of the plaster to fall off in places, carrying with it pieces of mortar from the joints of the brickwork and increasing the chances of sparks passing through.

In building a chimney more or less mortar and also pieces of brick are sure to drop into the flues, and a hole should be left at the bottom of each one, with a board stuck in on a slant, to catch the falling mortar. After the chimney is topped out the board and mortar should be removed and the hole bricked up. If there are bends in a flue openings should be left in the walls at those points for cleaning out any bricks and mortar that may lodge there. The outer walls of chimneys should be 8 inches thick, unless flue linings are used, in order to prevent the smoke from being chilled too rapidly.

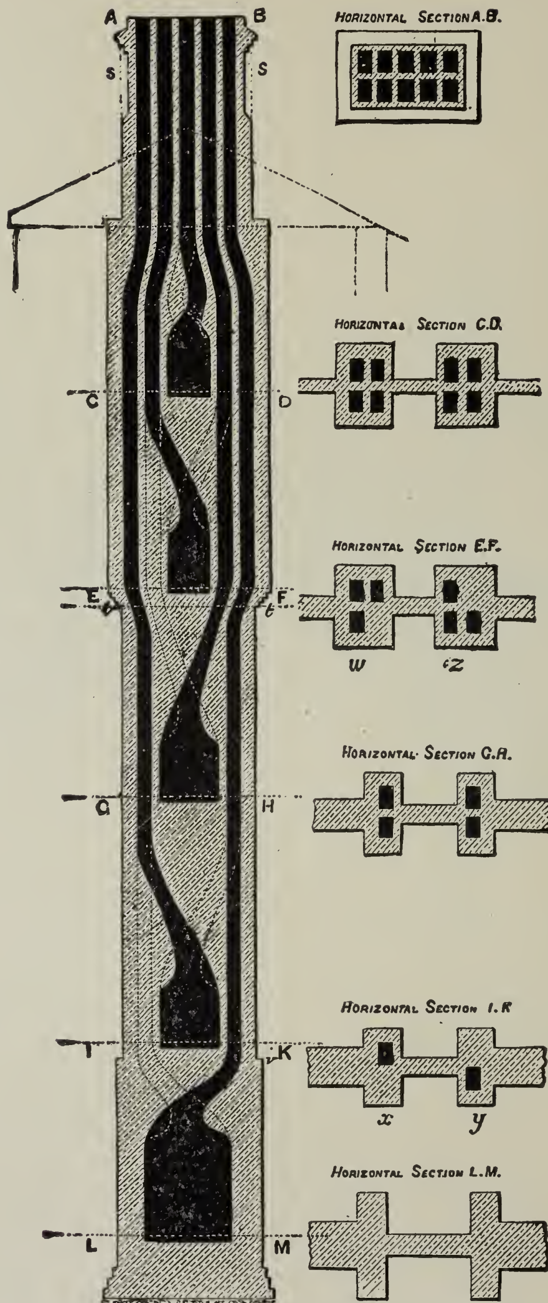


Fig. 233.—Brick Chimney Flues for Ten Fireplaces.

During the construction of a building the architect or superintendent should be careful to see that no woodwork is placed within 1 inch of the walls of any smoke-flue, and that all flues are smooth through their entire length.

The arrangement of chimney flues is ordinarily very simple. Fig. 232 shows the ordinary arrangement of flues in a chimney containing a furnace-flue, fireplaces in the first and second stories, and an ash-flue for the second-story fireplace.

Fig. 233, from Part II. of "Notes on Building Construction,"* shows the arrangement of the flues in a double chimney, with fireplaces in five stories.

Radial Block Chimneys.—There are several systems of constructing high factory chimneys by special forms of blocks, radial or otherwise. Among those who make a specialty of such work are the Alphonse Custodis Chimney Construction Company, New York; H. R. Heinicke, Inc., New York; George H. Thirsk, Philadelphia.

375. BRICK FIREPLACES.—*The Rough Opening.*—In building a fireplace, no matter how it is to be finished, it is customary first to build a rough opening in the chimney from 6 to 8 inches wider than the intended width of the finished opening, and 1 or 2 inches higher, drawing in the bricks above to form the flue, as shown in Figs. 232 and 233. The front wall of the chimney, over the opening, may be supported by a segmental arch when there are sufficient abutments; but when the side walls are only 4 or 8 inches thick heavy iron bars should be used to support the brickwork. The depth of the rough opening should be at least 12 inches, to permit of an 8-inch flue.

When there are fireplaces the bottom of the chimney is usually built hollow so as to form a receptacle for the ashes from the grate, as shown in Fig. 234. If the fireplace is to be used frequently an ash-pit is almost a necessity, especially in residences, and it should always be provided when practicable. When the fireplace is above the ground floor a flue can generally be built to connect the bottom of it with the ash-pit. In the chimney shown in Figs. 232 and 234 the ash-flue is built back of the lower fireplace. When there is no furnace-flue the ash-flue can be carried down on one side of the lower fireplace, thereby saving 4 inches in the thick-

* Rivington's South Kensington Series.

ness of the chimney. One ash-flue will answer for several fireplaces. A cast-iron door and frame, usually about 10 by 12 inches, should be built in the bottom of the ash-pit so that the ashes can be removed.

The ash-pit, rough opening and flues form the chimney, and are all built at the same time by the brick-mason, who builds the trimmer arch also.

The Trimmer Arch.—In buildings with wooden floor construction each fireplace hearth is usually supported by a "trimmer arch," commonly 2 feet wide by the width of the chimney in length, turned on a wooden center from the chimney to the joist header, as shown in Fig. 234. The wood center is put up by the carpenter, one side being supported by the header and the other by a projecting brick course on the chimney, or by flat pieces of iron driven into the joints. Although not needed for support after the arch has set, the center is generally left in place to afford a nailing for the laths or furring strips on the ceiling below.

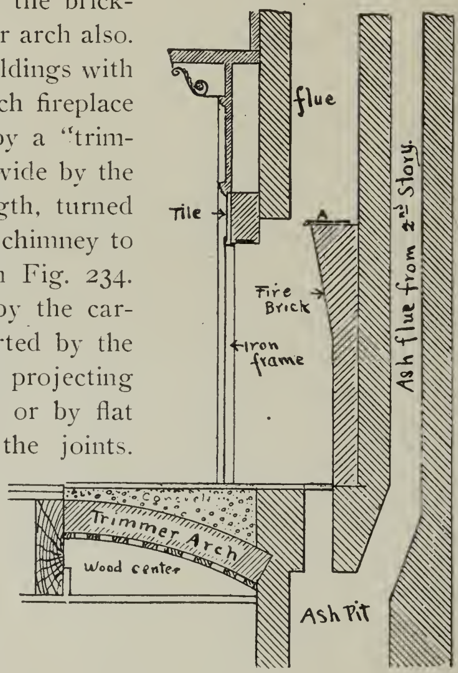


Fig. 234.—Section Through Brick Fireplace, Chimney Flues and Ash-pit.

Sometimes a flagstone is hung from the joists to support a hearth, but a stone generally costs more than an arch, and in the opinion of the author is not as good, as the arch will adjust itself to slight settlements in the chimney, and is not affected by any shrinkage of the floor joists.

The Finished Fireplace.—After a building is plastered the finished fireplace is built, usually by the parties furnishing the material, unless it is brick, when the work may be done by any skilled brick-mason.

At the present time the larger number of fireplaces are probably built with fire-brick linings and tile facings and hearths, with wooden mantels, after the manner shown in Figs. 234 and 235. In building such a fireplace the hearth is first levelled up with brick or

concrete, after which the hearth and the "under-fire" are laid, the metal frame at the edge of the opening set up and the lining and the backing for the tile facing built. After this work is completed the tile facing is set, and when the mortar has dried out, the mantel, if of wood, is set against it. Glazed tiles are usually employed for the hearth and facings, and they should always be set in rich Portland cement mortar. The sides of the linings forming the fire-box should be bevelled about 3 inches to the foot, and the back should be brought inward at the top, as shown, so that the opening into the flue will be only about 3 inches wide. The opening is called the

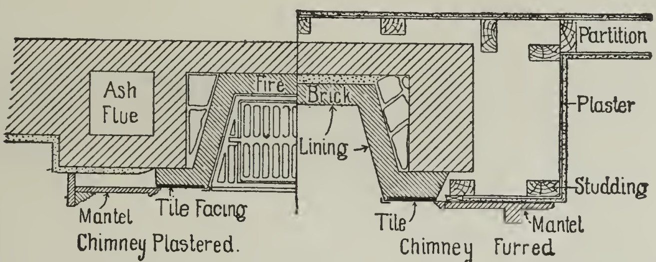


Fig. 235.—Sections Through Fireplace, Linings, Furrings, Mantel, etc.

"throat," and its proportions determine in a great measure whether the draught will be good or bad.

A damper should always be provided for closing the throat. The simplest arrangement is a piece of heavy sheet-iron with a ring on the edge, as shown at *A*, Fig. 234. It may be operated by the poker. A much better device, and one now quite frequently used, consists of a cast-iron frame with a door which may be pushed back to give the full opening. The door has a sliding damper also sufficient to let off the gases after the fire is well started. This device can be obtained of most mantel dealers, and generally insures a good draught. A small cast-iron ash-dump, also, should be placed in the bottom of the fireplace when there is an ash-pit.

The Grates.—There are a great many styles of grates that may be used in fireplaces. In one such as has been just described the "club-house" grate is probably most frequently used in localities where soft coal is burned. It consists of a cast-iron grate supported by four legs, and with an ornamental front about 6 inches high. It has no back or sides, and should fit close to the fire-brick lining. There is also a movable front to close the opening beneath the grate. These grates are well adapted to soft coal or coke.

For fireplaces that are to be frequently or steadily used a narrow opening, about 21 inches, is most desirable, as wider openings are very wasteful of coal.

Fireplaces in which wood is to be burned may have openings up to 4 feet wide, 3-feet openings being quite common. Wood is generally burned on andirons.

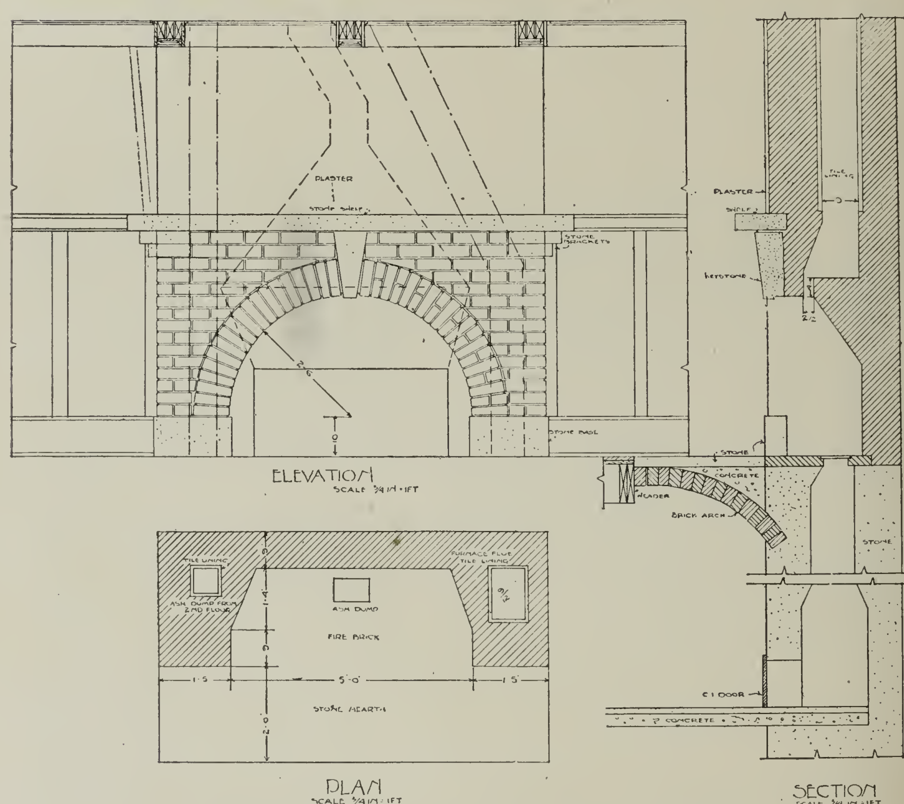


Fig. 236.—Details of a Large Brick-and stone Fireplace.

For burning hard coal, especially in ornamental fireplaces, basket-grates, having open fronts and solid backs and ends, are often used. They are made of various sizes and may be used in any fireplace.

One of the most practical devices is the "portable fireplace," which is a complete cast-iron fireplace with fire-box, dampers, shaking grate and separate front piece for summer. It can be set in any opening of suitable size, and is sure to draw well if the flue is reasonably large and high. These fireplaces are finished with

ornamental frames about 3 inches wide, in different finishes, and can be used with tile, marble or brick facings. They are made with 20 and 24-inch openings.

Brick-and-stone Fireplaces.—Fig. 236 shows the details of a large brick fireplace in which stone is used for the hearth, base, keystone, shelf and brackets. In the Middle West and Northwest fireplaces of this kind are very common, and are used in large living-rooms or halls. They are designed to burn large wood logs and have openings of sufficient width and depth to receive several at one time, and to receive them back of the line of the throat to prevent smoke from coming out into the room.

The throat is made narrow and long, with a shelf above, made flat as shown, and forming the top of the throat corbelling. This shelf extends back to the inside face of the outer wall so as to assist in preventing down draughts.

The walls of the chimney flues are made not less than 8 inches thick, unless they have tile flue-linings, in which case they are frequently reduced to 4½ inches if the height permits.

The ash-flue leads to the ash-pit in the cellar, and in case there is a fireplace above on the second floor connected with the same chimney, the ash-flue from this fireplace also is carried down as shown alongside the first-story fireplace and into the same ash-pit.

A large fireplace is sufficient to amply ventilate a very large room, and even all the rooms of an entire story of a moderate-sized house in which the communicating doors are left open.

A fireplace may be built also with pressed-brick facings, with either a square or an arched opening, and with a wood mantel set against it, the same as with tile facings. If wood is to be burned, pressed bricks may be used for the linings also, but they will not stand the intense heat of a coal fire. For the latter fire-bricks should be used for the linings.

Brick and Terra-cotta Mantels.—Although brick facings in connection with wooden mantels have been much used, the practice does not seem to be one to be recommended, either from a practical or decorative standpoint. If brick is to be used at all, it would seem better to make the entire mantel of brick or of brick and terra-cotta. In fact there are no materials which can be used with better effect for the finish about a fireplace than brick or terra-cotta, although they require artistic skill in the selection of the color and in their arrangement.

The great drawback in the past in building brick mantels has been the difficulty of obtaining bricks of suitable color and accuracy of form which could be adapted to a satisfactory decorative treatment. This difficulty, however, no longer exists, as there are now several companies that make a specialty of producing brick mantels of artistic design. These are skilfully designed with good architectural

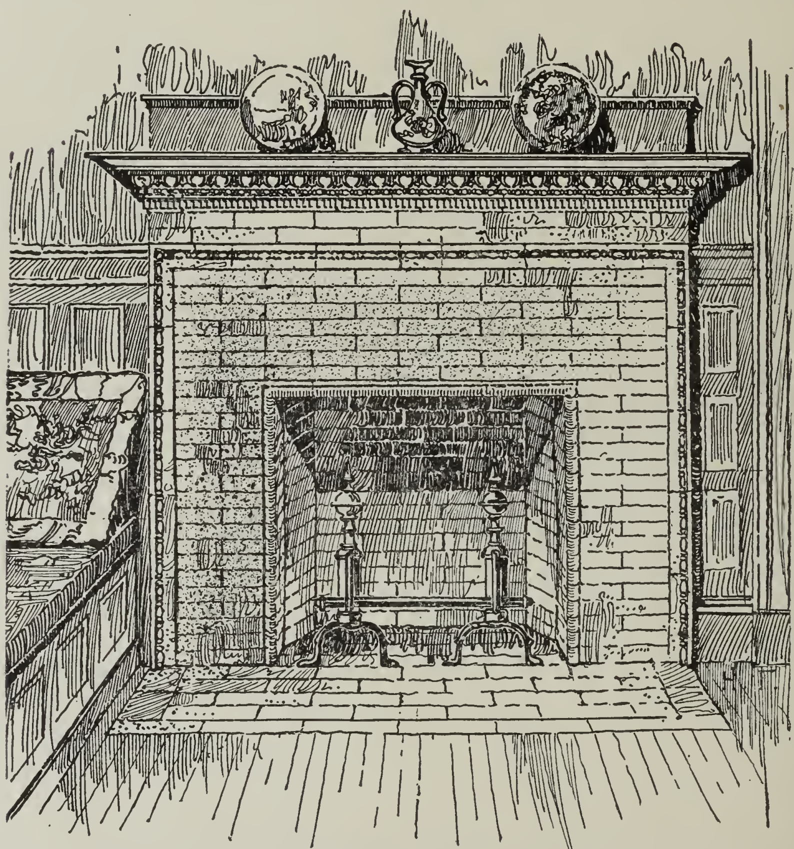


Fig. 237.—Brick and Terra-cotta Fireplace Mantel. Manufactured by Fiske & Co. J. H. Ritchie, Designer.

effects, and all the parts are accurately fitted, so that they can be easily put together by any skilled brick-mason. They are in a variety of designs and colors, and can be varied within certain limits of size to fit any particular space. The mantels of several manufacturers are extensively used, and with very satisfactory results.

In many of them the ornamentation is largely of terra-cotta

instead of molded bricks, and a special feature of this terra-cotta ornamentation is that the pieces are made in standard sizes which are interchangeable. This feature has often been utilized by architects, as it affords them an opportunity of making designs to suit their own individual tastes as regards the choice and arrangements of ornamentation, by bringing together in any desired combination the standard interchangeable pieces, thus gaining practically all the desirable features of special designs, with the additional advantages of moderate cost and certainty of delivery.

Figs. 237, 238, 239 and 240 illustrate various designs of brick

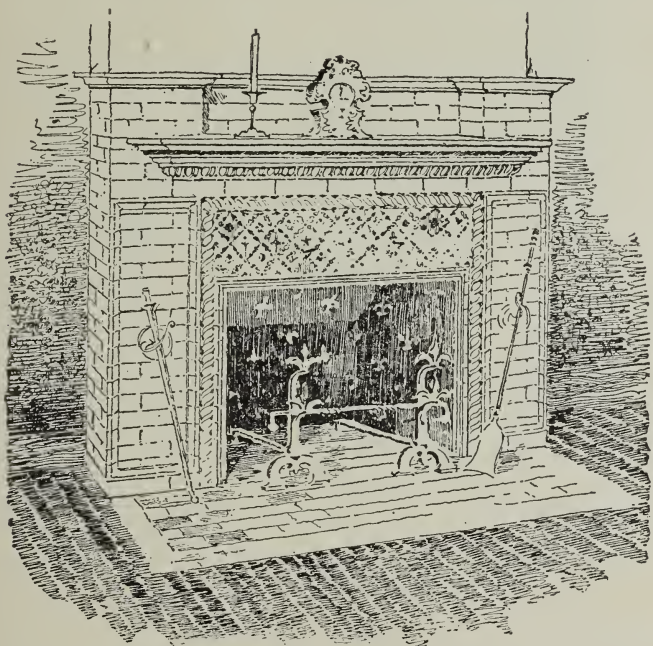


Fig. 238.—Brick and Terra-cotta Mantel. Philadelphia and Boston Face-brick Co., Boston.

and terra-cotta mantels. Fig. 237 is by Fiske & Co., Boston; Fig. 238 by the Philadelphia and Boston Face-brick Co., Boston; Fig. 239 by the Eastern Hydraulic-press Brick Co., Philadelphia, and Fig. 240 by Gladding, McBean & Co., San Francisco. Fig. 241 shows, on a large scale, the construction details of the molded bricks used in the arch of the mantel shown in Fig. 240.

In the mantel of Fig. 237 8 by 1½-inch bricks are used. The mantel shown in Fig. 239 is a suggestion for a chimney-piece suit-

able for a club, hotel, railroad station or other semi-public building. The design, even to the hearth, is entirely of brickwork. This chimney-piece is about 10 feet wide and 10 feet 6 inches high. The fire-opening is about 4 feet wide and 3 feet 5 inches high.

In the mantel shown in Fig. 240 "Roman"-shape bricks, 8¼ by

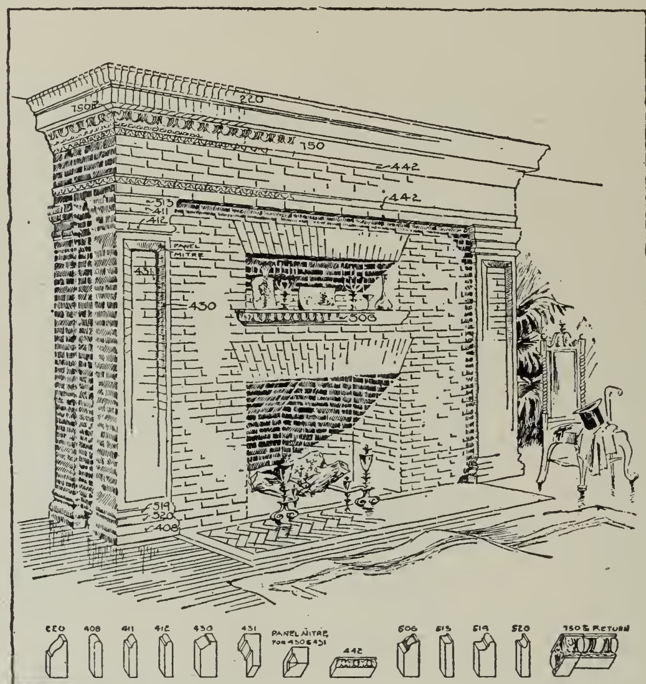


Fig. 239.—Brick Chimney-piece. Eastern Hydraulic-press Brick Co., Philadelphia.

4 by 1¾ inches, are used, with ⅛-inch mortar joints. The following are the different dimensions for this mantel:

	Feet.	Inches.
Width of breast	7	8
Height of mantel	4	10¾
Width of opening	4	4¼
Length of hearth	7	8
Returns at sides	1	0⅜
Depth of fire-box	1	9
Height of opening	2	9
Width of hearth	2	1
Width of opening between hobs	2	9½

376. BRICK STAIRS.—For building fire-proof stairs there is probably no better material than brick, unless it be Portland cement concrete in combination with metal tension bars. Brick stairs may easily be built between two brick walls by springing a segmental

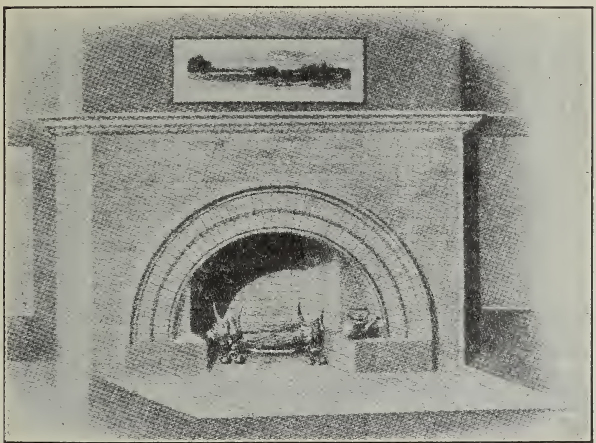


Fig. 240.—Design for Brick Mantel. Gladding, McBean & Co., San Francisco.

arch from wall to wall to form the soffit and by building the steps on top of this arch; or, if one side of the stairs must be open, that side may be supported by a steel I-beam, which should be protected by fire-proof tiling. This is shown in Fig. 242. The stairs in the

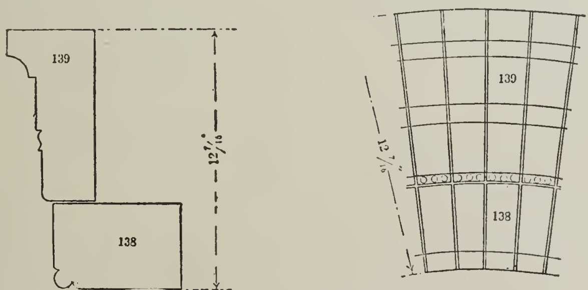


Fig. 241.—Detail Section and Elevation of Arch of Mantel Shown in Fig. 240.

Pension Building at Washington were constructed in this way. The treads of the steps may be of hard-pressed bricks, or slate treads may be laid on top of the bricks. Iron treads are not desirable, as they become slippery.

Brick Spiral Stairs.—Fig. 243 shows a brick spiral staircase of former days, in the House of Tristan, the Hermit, Tours, France.

Fig. 244 shows a method of constructing spiral stairs of brick-

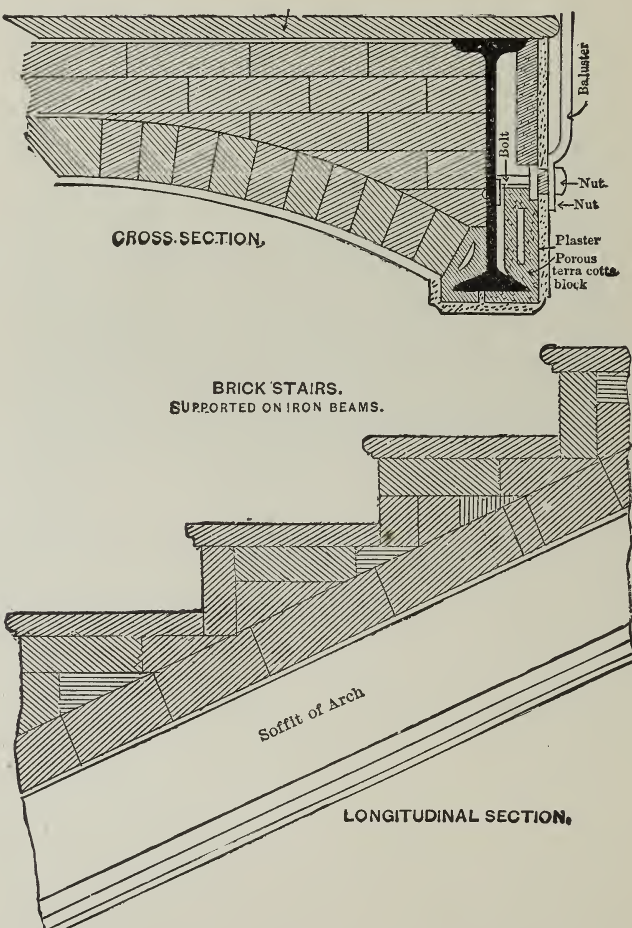


Fig. 242.—Details of Brick Stairs, Pension Building, Washington, D. C.

work commonly employed in Madras, India. These stairs are built without any centering, and cost in Madras less than one-third as much as iron stairs. It would seem as though this construction might be advantageously employed in this country where spiral stairs

are to be built in fire-proof buildings. The dimensions of a typical Madras spiral staircase are about as follows:

Diameter of stairs, wall to wall, inside........	6 feet.	
Diameter of newel in center..................	1 foot.	
Headway, from top of step to arching overhead,	7 feet	1½ inches.
Risers, each		6 inches.
Tread at wall..............................	1 foot	2⅛ inches.
Tread at newel..............................		2⅜ inches.

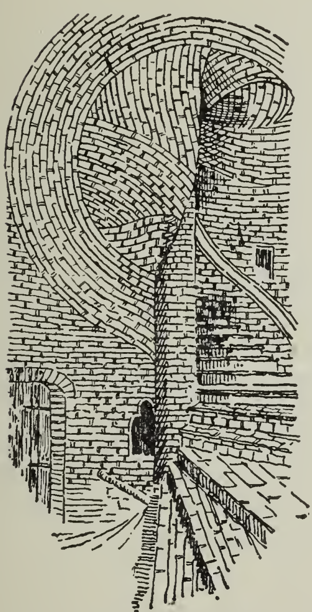


Fig. 243.—Staircase, House of Tristan, the Hermit, Tours, France.

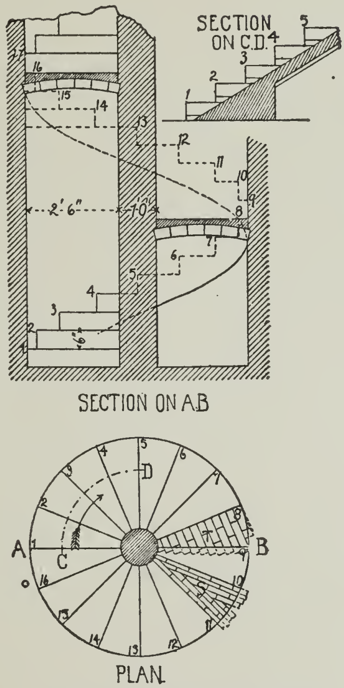


Fig. 244.—Brick Spiral Stairs. Construction Used in Madras, India.

Having determined the rise and number of steps in the usual way, work is commenced by building up solid two or three steps, when the arch is then started by ordinary terrace bricks, 5 by 3 by 1 inch, in lime mortar (1½ parts slaked lime to 1 of clean river sand). The bricks are put edgewise flat against one another, with their lengths in radii from the center of the stairs, and are simply stuck to one another by the aid of the mortar without any centering. These arch bricks are arranged as shown at *S,* the soffit being a continuous incline, as shown in the section *C D.* A slight rise, about 1½ inches, is given to the arch as shown in the section.

For forming the steps over this arching ordinary bricks are used, usually

9 by 4½ by 3 inches, trimmed to position and placed on edge as at *T* in the plan.

After a reasonable time for the mortar to harden, the work should bear a load of 300 pounds placed on a step and show no sign of giving. With good materials the steps will bear much heavier loads.—J. M., in *Indian Engineering.*

377. BRICK NOGGING.—"Nogging" is a term that is applied to brickwork filled in between the studding of wooden partitions. Brick nogging is often employed in wooden partitions of dwellings and tenement-houses to obstruct the passage of fire, sound and vermin. As no particular weight comes upon the bricks, and as they are not exposed to moisture, the cheapest kind of bricks may be used for this purpose. The bricks should be laid in mortar, as in 4-inch walls. If a partition is to be lathed with wooden laths it is necessary that the width of the bricks shall be not quite equal to that of the studding, in order to allow for the *clinch* of the plaster. When 3¾-inch studding is used it will be necessary either to clip the bricks or to lay them on edge.

When the studding of a partition rests on the cap of the partition below, it is an excellent idea to fill in the space between the floor and the ceiling below with nogging to prevent the passage of fire and mice; and two courses of bricks laid on horizontal bridging is also a good method of preventing fire or vermin from ascending in a partition.

378. CLEANING DOWN BRICKWORK.—Soon after the walls are completed all pressed or face-brick should be washed and scrubbed with muriatic acid and water, using either scrubbing-brushes or corn brooms. The scrubbing should be continued until all stains are removed. At the same time all open joints under window sills and in the stone and terra-cotta work should be pointed, so that when the cleaning down is completed the entire walls will be in perfect condition.

379. EFFLORESCENCE ON BRICKWORK.—A white efflorescence often appears on walls after they have been soaked with water. There are at least three different substances that may cause this efflorescence. Of these carbonate of soda appears most frequently on new walls, and is due to the action of the lime in the mortar upon the silicate of soda in the bricks. Silicate of soda seldom occurs in bricks unless a salt clay is used.

The only other white efflorescence of importance is composed chiefly of sulphate of magnesia, due to pyrites in the clay; and this,

when burned, gives rise to sulphuric acid, which unites with the magnesia in the mortar.

The above are the results of investigations made by Mr. Samuel Cabot, chemist. The conclusions he arrived at are these:

(1) The efflorescence is never due to the bricks alone, and seldom due to the mortar alone.

(2) To avoid efflorescence, the bricks should be rendered impervious with some preservative having the property of keeping salts from exuding. Linseed-oil cannot fill the requirements, as it is injured by the mortar.

In order to make brick walls impervious, however, it is necessary, before coating them, to minutely examine all joints and fill all holes. It is the opinion of the writer that if reasonably hard bricks are used for facings, the joints closely examined and filled and all brick projections and exposed tops waterproofed and provided with drips, but little efflorescence will appear.

380. DAMP-PROOFING BRICK WALLS.—All brick and stone walls absorb more or less moisture, and a wall 12 inches thick may sometimes be soaked through in a driving rainstorm. In the dry climates of Colorado, Arizona and New Mexico such storms rarely occur, and it is customary in those localities to plaster directly on the inside of the walls. In nearly all other parts of the country, however, it is desirable, for the sake of health and for economy in heating, even if not absolutely necessary, either to fur or strip the inside of solid walls with 1 by 2 inch strips, or to render the walls damp-proof, either by a coating of some kind applied to the outside of the walls, or by building the walls hollow. Furring the walls with wooden strips and then lathing on them prevents the moisture from coming through the plastering, but it does not prevent the walls themselves from becoming soaked, thereby necessitating more heat to warm a building and tending to gradually destroy the walls. A hollow wall, when properly built, is probably the best device for preventing the passage of moisture and also of heat; but in most cases it is also the most expensive method.

Brickwork may be rendered impervious to moisture either by painting the outside of the walls with white lead and oil or by coating the walls with preparations of paraffine, or by some of the patented waterproofing processes. The preparations containing paraffine are usually applied hot, and the walls also are heated by a portable heater previous to the application. They give fairly good

results, but are quite expensive, owing to the time and labor required for their application.

Sylvester's process, which consists in covering the surfaces of the walls with two washes or solutions, one composed of Castile soap and water and one of alum and water, has been used with much success for this purpose. A full description of the successful application of this process to the walls of the gate-houses of the Croton Reservoir in Central Park, New York, is given by Ira O. Baker in his "Treatise on Masonry Construction."

All of these preparations change somewhat the color and grain of the bricks, and are generally looked upon as detracting from the appearance of the building.

Boiled linseed-oil is often applied to brick walls, and two coats will prevent the absorption of moisture for from one to three years. The oil does not greatly change the color of the bricks, and generally improves the appearance of a wall which has become stained or discolored in any way.

Common white-lead-and-oil paint is probably the best material for damp-proofing external walls above ground, but it changes entirely the appearance of the building. Painting of new work should be deferred until the walls have been finished at least three months, and three coats should be given at first; after this one coat applied every four or five years will answer. A preparation known as "Duresco" has been used for damp-proofing with very satisfactory results. It has been used in some cases for coating the *inside* of the walls before the plastering is applied, to prevent the moisture penetrating the plastering, which purpose it seems to have successfully accomplished.

Duresco, when applied to common or soft bricks, not only renders them weather-proof, but its color gives the permanent appearance for which pressed bricks are valued. It dries with a hard, uniform, impervious surface free from gloss, and does not flake off or change color. It is put up in 56-pound kegs, that quantity being sufficient for covering 1,000 square feet with two coats.

Cabot's Brick Preservative is claimed by the manufacturer to form a thorough waterproofing for brickwork and sandstone, thus preventing white efflorescence, disintegration of chimneys by frost, and growth of fungus.

It does not change the natural texture of the material to which it is applied and it leaves no gloss. It has been found by actual experi-

ment that one coat of this preservative makes as good a waterproofing as three coats of boiled linseed-oil.

The preservative is manufactured in two forms: One kind is colorless, for use on any kind of bricks, to render them waterproof and to prevent efflorescence; and the other has red color added, to bring the bricks to an even shade without destroying the texture.

This material is applied with a brush in the same way that oil is applied, no heat being necessary. To obtain the best results, the brickwork should first be washed down with acid, preferably nitric acid, to remove any efflorescence already formed. One gallon will cover about 200 square feet on average rough bricks and a little more on pressed bricks. One coat is generally sufficient unless the bricks are extremely soft and porous.

To prevent moisture from penetrating the tops of brick vaults built underground, a coating of asphalt, from ½ to ¾ of an inch thick and applied at a temperature of from 360° to 518° Fahr., seems to give the best results. Common coal-tar pitch is often used for this purpose, but is not as good as asphalt. If a vault is to be covered with soil for vegetation, the top course of bricks should be laid in hot asphalt in addition to the coating.

381. THE CRUSHING STRENGTH OF BRICKWORK.*—In the majority of brick and stone buildings the crushing strength of brickwork need be considered only in connection with piers and arches and under bearing-plates or templates. The strength of brickwork varies with the strength of the individual bricks, the quality and composition of the mortar, the workmanship and bond and the age of the brickwork. It is not the purpose here to discuss the subject of the strength of materials, but it may be stated that for general practice the following safe loads may be allowed for the compressive strength of brickwork in the cases above mentioned; For New England or similar hard-burned bricks, in lime mortar, from 8 to 10 tons per square foot (112 to 138 pounds per square inch).

For the same bricks laid in mortar composed of natural cement 1 part, and sand 2 parts, 12 tons per square foot (166 pounds per square inch).

For the same bricks laid in cement-and-lime mortar, 1 to 3, 14 tons per square foot (194 pounds per square inch).

* Further details on this subject may be found in the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

For the same bricks laid in Portland cement and sand mortar, 1 to 2, 15 tons per square foot (280 pounds per square inch).

Average hard-burned Western bricks, in Louisville cement mortar, 1 to 2, 10 tons per square foot.

For the same bricks laid in Portland cement mortar, 1 to 2, 12½ tons per square foot (175 pounds per square inch).

In computing the safe resistance of brickwork from actual tests of the ultimate strength of work of the same kind, a factor of safety of at least 10 should be allowed for piers and 20 for arches. Piers higher than 6 times their least sectional dimension should be increased 4 inches in size—that is, in their lateral dimensions—for each additional 6 feet in height.

In most cities the maximum permissible loads for different kinds of masonry are fixed by the building laws.

It should always be remembered that the strength of brick piers depends largely upon the thoroughness with which they are bonded, and the building of all piers should be carefully watched by the superintendent.

382. MEASUREMENT OF BRICKWORK.—Brickwork is generally measured by the one thousand bricks laid in the wall. The usual custom of brick-masons is to take the *outside* superficial area of the wall, the corners being measured twice, and multiply it by 15 for an 8 or 9-inch wall, by 22½ for a 12 or 13-inch wall and by 30 for a 16 or 18-inch wall, the results giving the number of bricks. These figures give about the actual number of bricks required to build the walls in the Eastern States, but in the Western States, where the bricks are larger, they give about one-third more than the actual number of bricks contained in the walls, and the price is regulated accordingly. During the author's experience, in both the Eastern and Western States, he has never known any deviation made from these figures by brick-masons. In the West two kinds of measurements are known, *kiln count* being used to designate the actual number of bricks purchased and used, and *wall measure,* the number of bricks there would be on the basis of 22½ bricks to every superficial foot of a 12-inch wall.

No deduction is made for openings of less than 80 superficial feet, and when deductions are made for larger openings the width is measured two feet less than the actual width. Hollow walls are measured as if solid.

Footings are generally measured in with a wall by adding the

width of the projections to the height of the wall. Thus—if the footings project 6 inches on each side of a wall, 1 foot is added to the actual height of the wall.

A chimney-breast or pilaster is measured by multiplying the girth of the breast or pilaster from the intersections with the wall, by the height, and the product thus obtained by the number of bricks corresponding to the thickness of the projection. Flues in chimneys are always measured solid.

A detached chimney or chimney-top is measured the same as a wall having a length equal to the sum of one long side and the two ends of the chimney, and having a thickness equal to that of the chimney.

The rule for independent piers is to multiply the height of each pier by the distance around it in feet and to consider the product as the superficial area of a wall whose thickness is equal to the width of the pier. In practice many masons measure only one side and one end of a pier or chimney.

Arches of common bricks over openings of less than 80 superficial feet are usually disregarded in estimating. If an arch is over a larger opening the height of the wall is measured from the spring of the arch. No deduction is made in wall measurement for stone sills, caps or belt-courses, nor for stone ashlar, if the same is set by the brick-mason. If the ashlar is set by the stone-mason the thickness of the ashlar is deducted from the thickness of the wall.

Custom varies somewhat in the measurement of brickwork, and when work is done "by the thousand in the wall," the contract should state distinctly how the work is to be measured, and if deductions are to be made for the openings and stonework. Some builders reduce all the brickwork to cubic feet and estimate the cost in that way for common brickwork.

5. SUPERINTENDENCE OF BRICKWORK.

383. DETAILS REQUIRING SPECIAL ATTENTION.— The various portions of the work that require special superintendence have been mentioned in describing the manner of doing the work. In general the particular details in which brickwork is commonly slighted are the wetting and the laying of the bricks. The importance of wetting the bricks is fully set forth in Article 343. In laying the bricks it is often difficult to get the masons to use sufficient mortar to thoroughly fill all the joints and to get them to

"shove" the bricks. The quality of the mortar should also be frequently examined, as brick-masons in some localities like to mix a little loam with the sand to make the mortar "work well."

The bonding of the walls should be watched to see that the bond courses are used as often as specified. The bonding of piers should be particularly looked after. The laying of the face-bricks and ornamental details requires more skill, but is not so apt to be slighted as are the backs of the walls.

The superintendent should also see that the dimensions of the building are properly followed, that openings are left in their proper places, and that the courses are kept level and the walls built plumb.

In very high stories, and particularly in those of halls and churches, the walls should be stayed with temporary braces until the permanent timbers can be built in. It is also important to see that all bearing-plates are well bedded, all floor-anchors securely built in, all recesses for pipes, etc., which are marked on the plans, left in the proper places and all smoke-flues and vent-flues smoothly plastered.

Chapter VIII.

Architectural Terra-cotta.

384. COMPOSITION AND MANUFACTURE.—Terra-cotta is composed of practically the same material as bricks, and its characteristics, as far as the material is concerned, are the same. Terra-cotta, however, requires for its successful production a much better quality of clay than is generally used for bricks, while the process of manufacture is entirely different.

The first consideration in the manufacture of terra-cotta is the selection of the material. No one locality gives all the clay required for first-class material, and each shade and tint of terra-cotta requires the mingling of certain clays from different localities to regulate the color.

A great variety of excellent clays are mined in Northern and Central New Jersey, large quantities being marketed annually for making terra-cotta, as well as for fire-bricks, pottery, tiles, etc. The color varies from light cream to dark red.

A partial vitrification of the body is desirable, but a clay that is too fusible causes warping in the kiln. To overcome this tendency to twist, one at least of the component clays should be highly refractory, and to further insure straightness, from 20 to 25 per cent of ground burned clay called "grog" or "chamotte" should be added.

The clay after being mined is sometimes seasoned before being delivered to the factory. After being received, any one of several methods is employed to thoroughly grind and mix the clay with grog and water, and usually it is finally tempered in a pug-mill before being sent to the pressing room.

If several pieces of terra-cotta of the same size and shape are required, a full-sized model of plaster and clay is first made, and from this a plaster mold is taken. In the making of these models and molds the highest grade of skilled labor is required. When the molds are dry they are sent to the pressing department; here the plastic clay is pressed into the molds by hand, and when partially dry the work is turned out on the floor. The ware is then ready for

the carver or modeller, if it is decorative work that requires the use of their tools; or for the clay finisher if it only requires undercutting or some special work to make it fit in with other construction.

The work is carefully dried on the drying floor or in the dryers and is then ready to receive the surface treatment. This is done by spraying on the surface of the terra-cotta, by means of compressed air and an atomizer, a thin "slip" or liquid mixture which, when burned, gives the terra-cotta a surface which is vitrified, full-glazed, etc., as the case may be. This operation also gives the terra-cotta greater evenness in tone and its exact shade of color, the body colors used being comparatively few, while the surface colors are almost without limit.

It is then put into the kilns, where it remains from seven to fifteen days, according to the size of the kiln, before it is ready for use. The kilns used are the down-draught, beehive-shaped kilns, and an inside lining or "muffle" is used to prevent the flames from coming in direct contact with the terra-cotta. In this drying and burning process all the water in the clay is expelled, and in consequence, a shrinkage in the size of the pieces takes place. This shrinkage is about one inch to the foot, for which allowance is made by the draughtsman, who makes the drawings for the mold-maker. The pieces are then carefully inspected, fitted and numbered, in accordance with setting drawings prepared for that purpose.

The fitting operation consists in placing the various pieces in the relative positions which they would have in the building, and then by the use of the chisel, in trimming joints where necessary, so that the pieces will all fit accurately together. By the use of the rubbing-bed, the joints are rubbed to an absolutely straight line in the same manner that stonework is rubbed. The rubbing of the joints is of great advantage in ashlar-work, as it insures absolute alignment of the joints.

The numbering operation consists in marking each piece with a number for identification. A corresponding number is placed on the setting drawings. The work is then finally shipped to the building.

If only one or two pieces of terra-cotta are to be made, or if no repetition is intended, no molds are used, the clay being modelled by hand, with the use of templates, into the required shape. Single pieces of modelling are worked up on ashlar and plain blocks. The finished product thus bears directly the impress of the modelling

artist. It can be studied, improved or modified, and, when entirely satisfactory, burned. On this account terra-cotta possesses, for highly decorative work, an advantage over all other building materials.

Terra-cotta has this advantage even where repetition is intended and molds are made, because the ornamental portions of the models are made of clay, which under all circumstances is the best material that can be used for modelling purposes; they can therefore be studied and improved before the molds are made. The architect sometimes examines the models in person, and the alterations are then made directly under his eye. Sometimes photographs are made and sent for his inspection and approval. If the ornament is of sufficient importance to make it desirable to bear the direct touch of the modelling artist, he can retouch each piece after it is turned out of the mold.

Terra-cotta is usually made in blocks from 24 to 30 inches long, from 6 to 12 inches deep and of a height determined by the character of the work. To save material and prevent warping, the blocks are formed of an outer shell, connected and braced by partitions about 1¼ inches thick. The partitions should be arranged so that the spaces do not exceed 6 inches, and should have numerous holes in them to form clinches for the mortar and brickwork used for filling.

385. THE SURFACE OF TERRA-COTTA.—The body of all good terra-cotta is very much the same, but there are several ways of treating the surface, resulting in products which may be classified as follows: Standard Terra-cotta, Vitreous Surface Terra-cotta, Mat-glazed Terra-cotta, Full-glazed Terra-cotta and Polychrome Terra-cotta.

Standard Terra-cotta has no surface given it, which affects its porosity, a drop of water placed upon it being soon absorbed. It will absorb, also, a great amount of dirt from the atmosphere and will become very much darker from continued exposure. On some buildings this "weathering down" is not objectionable; in fact it sometimes lends a charm, producing an antique appearance which is often very desirable from an artistic point of view. Someone has said that "time is the greatest artist," and therefore, when it is desired to produce an aged effect, Standard Terra-cotta should be used. It is, consequently, a good material to use for "rustic work," in connection with country houses, college buildings, gateways, cer-

tain styles of churches, etc. This class of material is made in any color desired.

Vitreous Surface Terra-cotta has a very thin spray on the surface which vitrifies in the burning process, forming a thin glaze which sheds water. This terra-cotta will not absorb much dirt from the atmosphere, as the rain of each storm washes it off; it therefore practically retains its original color. This class of material is made in any color desired and is used more than any other kind at the present time, as it seems to satisfy the greatest number of requirements. The "Flatiron" Building, New York, D. H. Burnham & Company, architects, was of this material.

Mat-glazed Terra-cotta.—In Western cities where soft coal is used, and where, consequently, most buildings are cleaned about once every year, any material of a non-porous nature is very desirable; and it has been found that glazed terra-cotta ranks with the most superior materials in this respect. On this account white glazed terra-cotta is used to a great extent in these cities. The luster of the glaze is deadened for artistic reasons, the glare of the sunlight on full-glazed terra-cotta being very severe. This is now done in the process of burning, as it has been found that sand-blasting the material neutralizes the purpose of the glaze; and this method has long been abandoned by the leading manufacturers. There are many examples of buildings constructed of this material in the West, and the most notable example in the East is the Plaza Hotel, Fifty-ninth Street, New York, H. J. Hardenburg, architect.

Full-glazed Terra-cotta.—For light-courts, loggias to office-buildings, theatres, interiors of railroad stations, ferry-houses, train-sheds, natatoriums, power-houses, etc., the full-glazed terra-cotta is preferable, as it helps illumination and gives a more brilliant effect.

Polychrome Terra-cotta.—The full-glazed terra-cotta and mat-glazed terra-cotta are made in any color required, and when various colors are used on the same building the material is termed "polychrome." The various colors may be applied to the same piece if desired, or each separate color may be kept on a separate piece, if the design will permit. The next article, 386, "Color of Terra-cotta," explains the uses to which this class of material may be put.

386. COLOR OF TERRA-COTTA.—Within the past twenty

years a great impetus has been given to the production of special colors in architectural clay products. In 1885 fully four-fifths of the terra-cotta produced in the United States was red; now (in 1908) there is less of red used than of almost any other color. Buffs and grays of several shades, white and cream-white and the richer and warmer colors of old-gold and brown are now the prevailing colors.

By the use of ceramic colors almost any required tone may be produced and the effect obtained by using glazed terra-cotta of various colors in combination, such as blue, yellow, white, purple, brown, old-gold, green, red, etc., is often very beautiful. If any particular shade of color not included in the manufacturer's standard samples is desired, the architect should consult with the manufacturer, who will then experiment until the required color is not only produced, but guaranteed to be permanent and free from all tendency to crack or craze.

It is quite generally agreed that there is a great field for this polychrome terra-cotta, especially for theatres, restaurants and buildings of a similar nature; for interiors, loggias, fountains, etc.; for department-stores, when a striking design is required for advertising purposes; and for certain styles of church work. Although the art of using colored terra-cotta is very ancient, having been in practice before the Christian Era, it is, to some extent, an undeveloped field in this country and offers alluring possibilities in architectural design and construction. It can be used in a very modest and sparing manner, as well as very profusely; and either in soft tints or in brilliant colors, as the taste of the architect may dictate. Where a rich decorative treatment is required, as in the interiors of large public buildings like our great union-stations, hotels, theatres, etc., polychrome terra-cotta can be employed most effectively and economically.

In variety and beauty of tones, polychrome terra-cotta has now reached a very high standard of excellence, and may be used by the architect to express the highest type of his art. The almost unlimited possibilities presented by the judicious application of colored glazes for exteriors, as well as for interiors, has awakened an unusual interest in the use of polychrome terra-cotta, a building material with superior qualities of resistance against the deteriorating effects of time and of the action of fire and frost.

Under the direction of some of our most noted architects a large

amount of this polychrome terra-cotta has been produced during the last few years, and the following are some notable examples:*

Academy of Music, Brooklyn, Herts & Tallant, architects; Madison Square Presbyterian Church, Madison Square, New York, McKim, Mead & White, architects; Statler Hotel, Buffalo, N. Y.; Essenwein & Johnson, architects; Munsey Building, Washington, D. C., McKim, Mead & White, architects; St. Ambrose Church, Brooklyn, N. Y., Geo. H. Streeter, architect; Seminary for the Society of Redemptorist Fathers, Esopus, N. Y., F. Joseph Untersee, architect; the New York Subway Stations, Heins & La Farge, architects; the Hudson Terminal Concourse, New York, Clinton & Russell, architects; a number of railroad stations, New York, New Haven & Hartford Railroad, Cass Gilbert, architect; and the Automobile Club of America, New York, Ernest Flagg, architect. In the West, also, colored terra-cotta is being used to a great extent. Polychromatic ornament like that of the Madison Square Presbyterian Church, New York, and the Brooklyn Academy of Music, would seem to demonstrate that our climate and atmosphere are well adapted to the use of polychrome exterior construction, especially when produced in glazed tile or terra-cotta.

387. USE OF TERRA-COTTA.—Terra-cotta is not imitation stone and should not be used as such.

It is a material having peculiar qualities which give a distinctive character, and therefore, to be successfully used, it should be employed in such a way that its individual characteristics will be expressed, and not in such a way that it will appear as an imitation of, or as a cheap substitute for, some more expensive material. This may be brought about in several ways. There may be used certain architectural forms and certain styles of ornament more characteristic of terra-cotta than of any other material. One architect† has evolved a certain style that he has applied to many buildings, and which is not suitable to any material other than terra-cotta. This may be said of both the form and ornamentation of his buildings. The architects‡ of the "Flatiron" Building and of the Wanamaker Building in New York have successfully used this material for its own sake and not as an imitation. Another firm of architects§ have

* The polychrome terra-cotta for the buildings mentioned was made by the Atlantic Terra-cotta Company, New York. This company rendered most valuable assistance in the rewriting of this chapter.

† Mr. L. H. Sullivan, Chicago.

‡ D. H. Burnham & Co., Chicago.

§ McKim, Mead & White, New York.

used profusely modelled terra-cotta to produce highly ornamental effects not so easily obtainable in other materials, and their recent use of colored terra-cotta is typical of this material alone.

In the West Street Building, New York, the architect* has made a design distinctly expressive of the material used, viz.: terra-cotta. This is noticeable in the ornamentation, in the form of cornices and molding, in the coloring and even in the plain shaft of the building.

In the Brooklyn Academy of Music the architects† have accomplished this result by the use of color.

In regard to the use of colored terra-cotta, it has been said that "it is by the use of polychrome terra-cotta that the material has its best opportunity for expressing its individual character. It was so in antiquity, in the Middle Ages, and is so at the present time, because polychrome terra-cotta is a material complete in itself, and used for its own sake; and it cannot by any means be considered in imitation of, nor a substitute for, something better."

388. DURABILITY.—The principal value of terra-cotta lies in its durability. When made of the right materials and properly burned it is impervious to water, or nearly so; and when glazed it is absolutely impervious, and hence not subject to the disintegrating action of frost, which is a powerful agent in the destruction of stone. It does not "vegetate," as is the case with many stones. The ordinary acid gases contained in the atmosphere of cities have no effect upon it, and the dust which gathers on the moldings is washed away by every rainfall. Underburned terra-cotta does not possess these qualities to so high a degree, as it is more or less absorbent. Another great advantage possessed by terra-cotta is its resistance to heat, which makes it a most desirable material for the trimmings and ornamental work in the walls of fire-proof buildings. Although terra-cotta has been used in this country for but a comparatively short time, it has thus far proved very satisfactory, and the characteristics above indicated would point to its ranking, in common with the better qualities of bricks, with the most desirable of building materials if, indeed, it is not *the* most durable of all building materials.

In Europe there are numerous examples of architectural terra-cotta which have been exposed to the weather for three or four

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* Mr. Cass Gilbert, New York.
† Herts & Tallant, New York.

centuries and which are still in good condition, while examples of stonework, subjected to the same conditions, are more or less worn and decayed.

"There is at the Louvre in Paris, to-day, some glazed terra-cotta said to have been made by the Assyrians in the sixth century before Christ, and in other museums there are some vases and other ancient terra-cottas from Egypt and Greece, as well as the famous Lucca Della Robbia work made in the Middle Ages, many of these pieces being as perfect as if recently made. All these ancient terra-cottas tell the story of durability and proclaim terra-cotta to be a material worthy of the genius of those artists of antiquity who wrought so beautifully in this sympathetic medium.

"Specimens made two thousand years ago have been found in the ruins of ancient buildings in an almost perfect state of preservation, while the stones among which they have been found have long since crumbled away from their original size and shape."

389. INSPECTION.—A sharp metallic, bell-like ring and a clean, close fracture are good proofs of homogeneity, compactness and strength. Perfection of form is in the highest degree essential, and can result only from a homogeneous material and a thorough and experienced knowledge of firing.

No spalled, chipped or warped pieces of terra-cotta should be accepted, and the pieces should be so hard that they will resist scratching with the point of a knife. The blocks should be of uniform color also, and all moldings should come together perfectly at the points.

Terra-cotta with a vitreous surface and mat-glazed terra-cotta should be so non-absorbent that water will lie in drops on its surface without being quickly absorbed. Full-glazed terra-cotta should be so non-absorbent that ink will not penetrate the surface and may be entirely washed away with water.

390. LAYING OUT TERRA-COTTA.—On account of the manner in which terra-cotta shrinks in the drying and burning process, it always has a tendency to warp and to vary in size.

By careful methods in manufacture these tendencies are kept under control to a great extent, but it is always best in jointing terra-cotta to arrange the joints so as to provide for the adjustment of any such inaccuracies. Figure 245*, showing a terra-cotta

* Courtesy of the Atlantic Terra-cotta Company, New York.

doorway with hidden joints, illustrates a system of back joints to provide for such adjustment. If any piece of the jambs or ashlar shrinks too much, or too little, there is an edge on that piece that

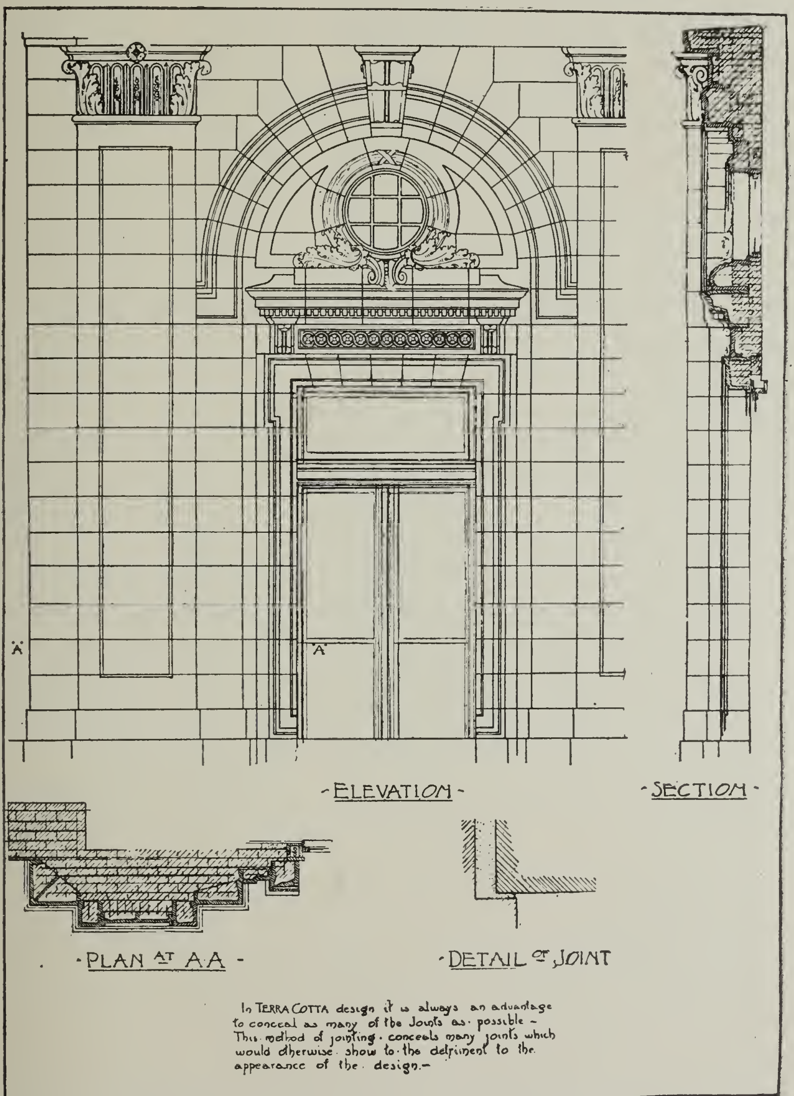


Fig. 245.—Terra-cotta Doorway with Hidden Joints.

may be cut away to the proper size if necessary, without affecting the "take-up" of any members.

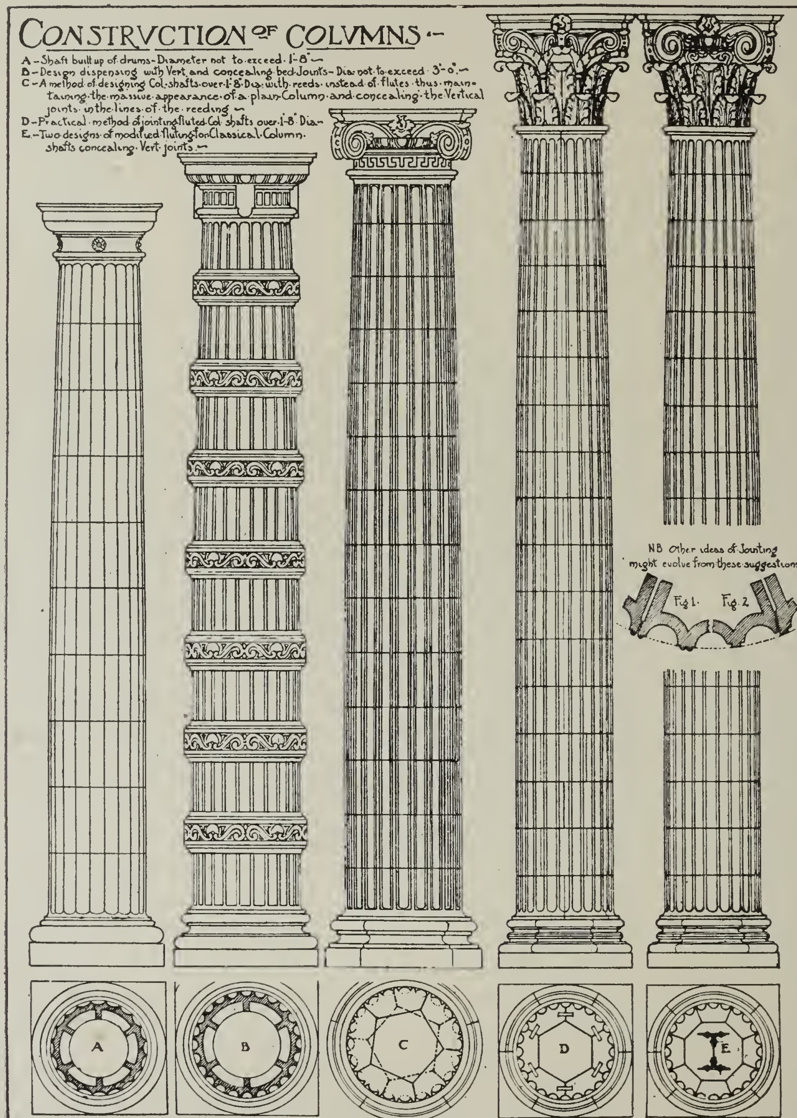


Fig. 246.—Construction of Terra-cotta Columns.

The inner jamb and arch-pieces are made separate for the same reason; and the joint in the cap is hidden in the lines of the ornament, so that if trimming becomes necessary, it will not spoil the appearance of the delicate modelling. It is unnecessary to joint

terra-cotta with alternate deep and shallow bonds or with bond-blocks for jambs, etc., because the brick backing may be and should be built into the hollow spaces in the back of the terra-cotta. By following this method and by using anchors, plumb joints through many courses at the edge of the piers, jambs, pilasters, etc., are absolutely secure.

Fig. 245* is laid out in this manner, with the result that the joints which usually detract from the appearance of the terra-cotta are so hidden in the lines of the design that the number apparent is reduced to a minimum. Although the pieces here shown are small in size when compared with stonework, this method of jointing gives the same effect that would be produced if very large pieces were used. Even though the scale of this design were larger, this same method could be used, as pieces up to 3 feet and 3 feet 6 inches long are practicable when the width is not over 1 foot 6 inches, long narrow pieces giving the best result.

Columns should be made with bands, if possible, or else jointed as shown in Fig. 246,* showing the construction of terra-cotta columns, as the inaccuracy in shrinkage is much more apparent when so many small members like the fillets between the flutes must take it up.

Column *A* shows shaft built up of drums. Diameter not to exceed 1 foot 8 inches.

Column *B* shows design dispensing with vertical joints and concealing bed-joints. Diameter not to exceed 3 feet.

Column *C* shows a method of designing column shafts over 1 foot 8 inches in diameter, with reeds instead of flutes, thus maintaining the massive appearance of a plain column and concealing the vertical joints in the lines of the reeding.

Column *D* shows a practical method of jointing fluted column shafts over 1 foot 8 inches in diameter.

Column *E*, with sections 1 and 2, shows two methods of modified fluting for classical columns, with the vertical joints of the shafts concealed.

As the blocks of terra-cotta are made from molds of fixed sizes, repetition is economy; therefore, a great saving in expense is obtained by making the various portions of the building typical. The windows, as far as possible, should all be the same height,

* Courtesy of the Atlantic Terra-cotta Company, New York.

opening and reveal; the piers should be the same width; the pavilions or bays should be the same size and design; the different stories should be the same height and design as far as possible, and all ornaments should be spaced to conform to the centering of the jointing scheme.

Ashlar-work should have some treatment of jointing that will allow for trimming and adjustment, and where possible, members should be introduced to break up the severe lines. Figure 247*

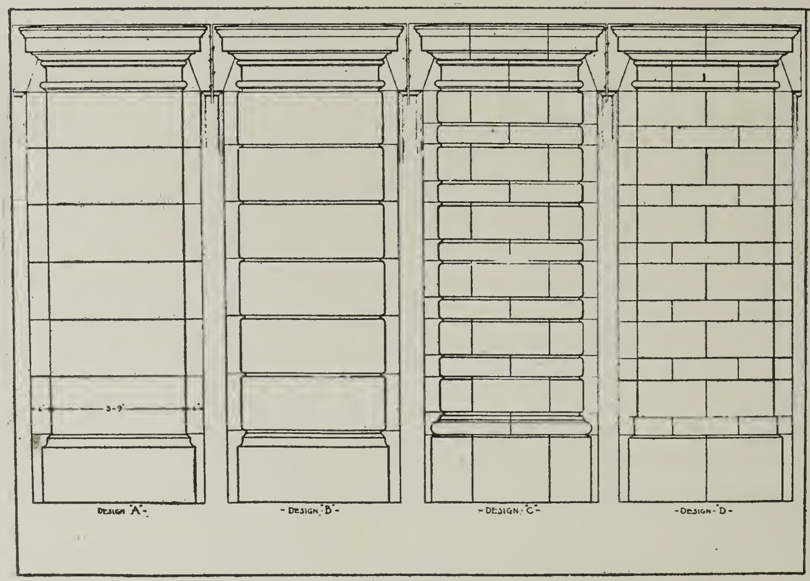


Fig. 247.—Terra-cotta Piers. Different Treatments.

shows several suggestions for the treatment of a pier, which might occur in the lower stories of a building.

In this figure, design *A* shows a first-story pier designed for stone construction. As these severe lines demand exact alignment, this construction is unsatisfactory for terra-cotta, because there are no vertical joints which may be trimmed to afford adjustment where uneven shrinkage occurs.

Design *B* shows the same pier altered to permit a practical method of jointing. These rustications break the severe lines, so that any inexactness which may occur will not be apparent. The massive appearance of the pier is increased by this alteration. This could

* Courtesy of the Atlantic Terra-cotta Company, New York.

not be applied to a corner pier, as the return would be too great. These pieces could be made not more than 1 foot 6 inches return.

Design *C* shows the same pier altered to permit of smaller pieces. The vertical joints may be trimmed to afford adjustment where the shrinkage has been uneven; and therefore corner piers may be jointed in this manner. This design is very satisfactory when in harmony with the general design of the building.

Design *D* shows the same pier jointed in such a manner as to leave unaltered the profile of the pier. This preserves the severe lines and massive appearance, while the joints are so arranged as to allow trimming to afford proper adjustment and adherence to exact measurements.

Sills 7 inches deep may be made as much as four feet in length. Blocks in belt-courses, cornices, etc., usually should not exceed 2 feet 6 inches, or 3 feet in length.

Balusters should be cut into two or three pieces in height, depending upon the size, and panels and tracery should be cut into pieces so as to provide for adjustment in setting.

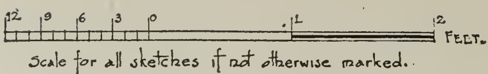
Raised joints should be used, as covered joints are delicate, and are therefore usually broken, to a greater or less extent, in handling and setting at the building.

It is better for architects to place the jointing and construction of terra-cotta work in the hands of the manufacturer, who may be considered an expert in his line. He knows better than the architect does the proper methods to employ. If, however, the architect wishes to superintend this part of the work, the usual course pursued is to have the manufacturer make factory working-drawings and submit them to the architect for his inspection and approval.

391. COMPARISON OF BAD AND GOOD METHODS OF TERRA-COTTA CONSTRUCTION.—Figs. 248 to 256* show various typical illustrations of terra-cotta details, with faulty or incorrect methods of construction sometimes seen and with the correct and approved methods also indicated for purpose of comparison.

Unless otherwise noted on the drawings, the scale shown in Fig. 248 is the one used for all of the nine figures, 248 to 256, both inclusive.

* These figures, 248 to 256, are reproduced through the courtesy of the Northwestern Terra-cotta Company, of Chicago.



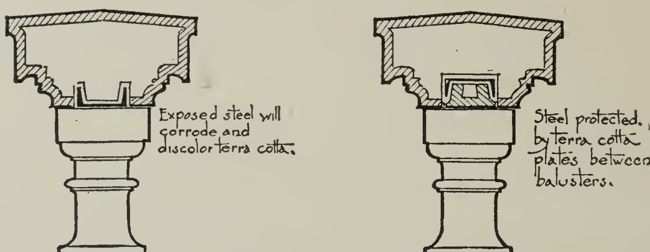


Fig. 248.—Terra-cotta Rail and Baluster. Bad and Good Construction.

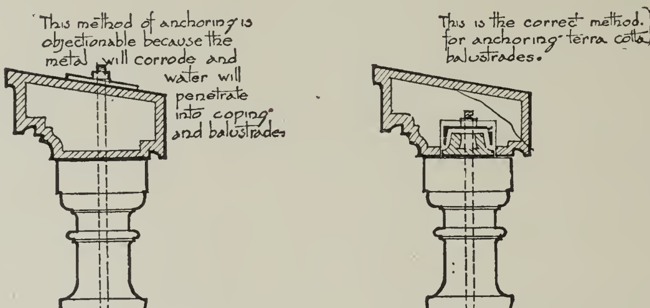


Fig. 249.—Terra-cotta Rail and Baluster. Bad and Good Construction.

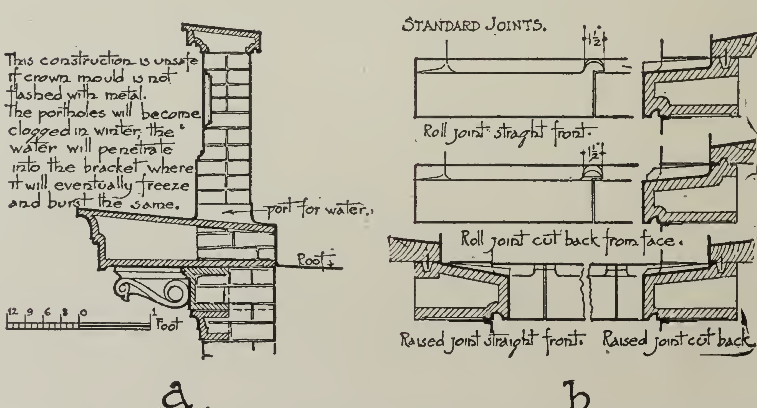


Fig. 250.—a. Cornice Coping, Poor Construction. b. Standard Terra-cotta Joints.

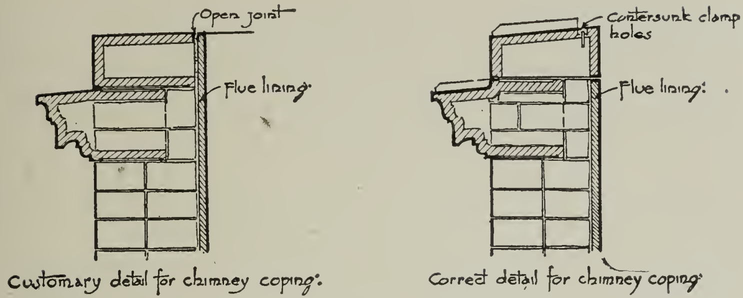


Fig. 251.—Terra-cotta Chimney Coping. Poor and Good Construction.

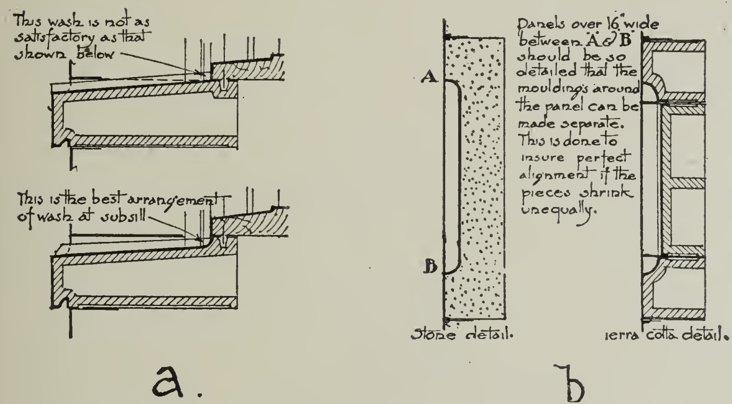


Fig. 252.—a. Terra-cotta Sills. b. Stone and Terra-cotta Panels.

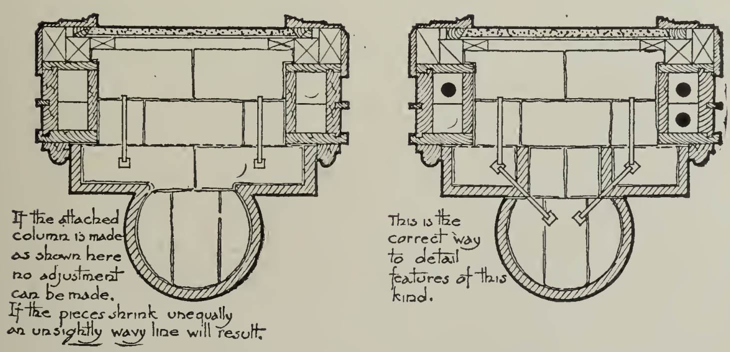


Fig. 253.—Terra-cotta Engaged Columns. Bad and Good Construction.

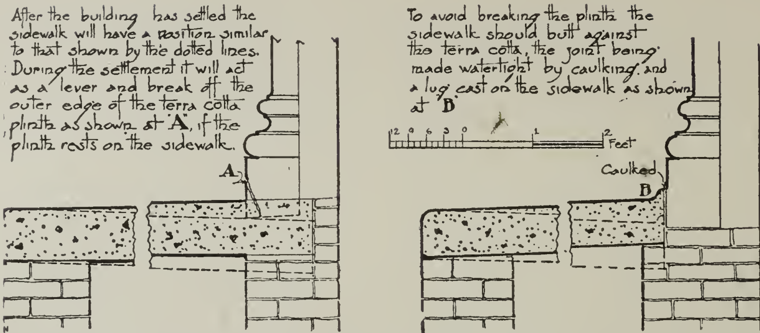


Fig. 254.—Terra-cotta Column-base and Sidewalk. Bad and Good Construction.

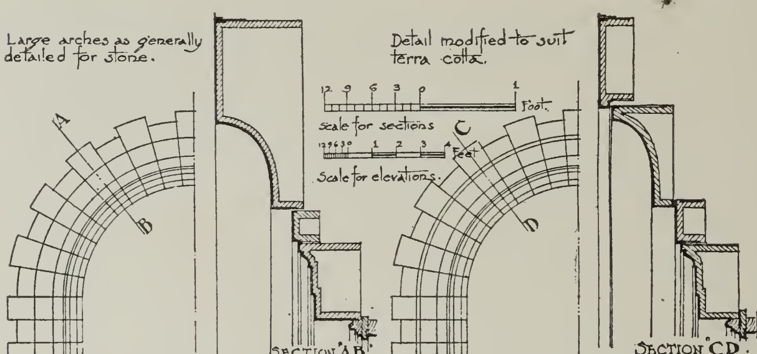


Fig. 255.—Large Terra-cotta and Stone Arch Construction Compared.

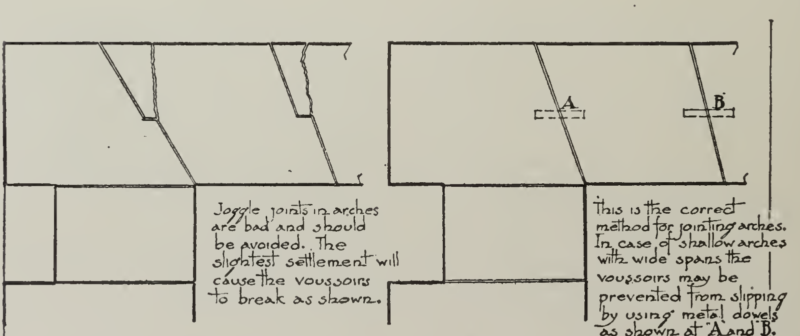


Fig. 256.—Terra-cotta Flat Arches. Bad and Good Construction.

The titles of the figures and the notes on each, with the detailed construction shown in the drawings themselves, explain clearly the good and bad methods of putting together terra-cotta in some of the important parts of buildings.

392. SETTING AND POINTING. — *Setting.* — Terra-cotta should always be set in either natural cement or Portland cement, mixed with sand, and in about the same way as stone is set. As soon as set, the outside of the joints should be raked out to a depth of ¾ of an inch to allow for pointing and to prevent chipping. The terra-cotta should be built up in advance of the backing, one course at a time, and all voids except those projecting beyond the face of the wall should be filled with grout or mortar, into which bricks should be forced to make the work as solid as possible. All blocks not solidly built into the walls should be anchored with galvanized-iron clamps, the same as described for stonework, and, as a rule, all projecting members over 6 inches in height should be anchored in this way.

Terra-cotta work is generally set by the brick-mason, but the specifications should distinctly state who is to do the setting and pointing.

Much better results are always obtained when the setting of the terra-cotta is included in the terra-cotta contract and is done by the manufacturer, as it is to his advantage to take the greatest care to satisfactorily erect the material.

Pointing.—After the walls are up the joints should be pointed with Portland cement colored with a mineral pigment to correspond with the color of the terra-cotta. The pointing is done in the same way as described for stone, except that the horizontal joints in all sills and washes of belt-courses and cornices, unless covered with a roll, should be raked out about 2 inches deep, calked with oakum for about 1 inch and then filled with an elastic cement.

393. TIME.—One of the principal objections to the use of terra-cotta is the time required to obtain it, especially when the building is some distance from the manufactory. About six weeks are required for the production of terra-cotta of the ordinary kind, and the architect should see that all the drawings for the terra-cotta work are completed and delivered to the maker at as early a stage in the work as possible, so that he may have ample time to produce it.

This will obviate any delay if the architect's drawings and in-

structions are clear, distinct and complete, as it takes longer to obtain the steel construction work than it does to make the terra-cotta.

Most of the delay in obtaining terra-cotta is really due to the fact that prompt and careful attention is not always given to the preparation of the terra-cotta drawings and instructions.

Small pieces of terra-cotta may sometimes be obtained within two weeks from the receipt of the order, when the molds are already on hand. It is always more expensive, however, to attempt to turn out work in such short order, and inexpedient on account of the risks in forcing the drying.

394. COST OF TERRA-COTTA.—Terra-cotta is generally less expensive than stone, and ornamental work costs in stone about three times as much as it does in terra-cotta.

Being lighter in weight the freight charges are less.

In large buildings the use of terra-cotta reduces the cost of the steel construction, because when it is used on the exterior the steel may be about one-third smaller and lighter, thereby reducing the cost proportionately. This saving is an important item in large structures. The cost of erecting terra-cotta is less than that of erecting stone, two stories of an all terra-cotta exterior being sometimes put in place in the same time that it takes to set one story of stone.

The advantage in point of cost in favor of terra-cotta is greatly increased if there is a large proportion of molded work, and especially if the moldings are enriched or if there are a number of ornamental panels, carved capitals, etc.

The use of terra-cotta for trimmings, and especially for heavy cornices, in place of stone, often reduces the cost of the walls and foundations, as the weight of the terra-cotta will be much less than that of stone, and the walls and foundations may be made lighter in consequence.

395. WEIGHT AND STRENGTH.—The weight of terra-cotta in *solid blocks* averages 122 pounds per cubic foot. When made in hollow blocks 1½ inches thick the weight varies from 65 to 85 pounds per cubic foot, the smaller pieces weighing the most. For pieces 12 by 18 inches or larger on the face, 70 pounds per cubic foot should be a fair average.

The crushing strength of terra-cotta blocks in 2-inch cubes varies from 5,000 to 7,000 pounds per square inch.

Hollow blocks of terra-cotta, 1 foot high, unfilled, have sustained 186 tons per square foot.

From these and other tests the author would place the safe working strength of terra-cotta blocks in the wall at 5 tons per square foot when *unfilled* and at 10 tons per square foot when *filled solid* with brickwork or concrete.

If it is desired to test the strength of special pieces, two or three small pieces should be broken from the blocks and ground to 1-inch cubes, and then tested in a machine. Should the average results fall much below 6,000 pounds the material should be rejected.

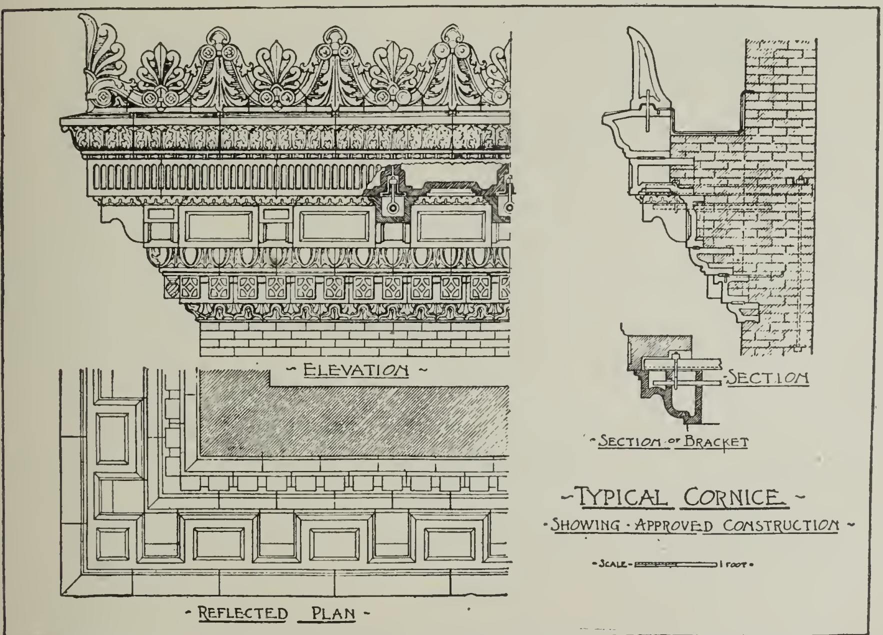


Fig. 257. Terra-cotta Cornice, Church of Christ Scientist, Los Angeles, California.

Transverse Strength of Modillions.—A cornice modillion measuring 11½ inches high and 8 inches wide at the wall line, with a projection of 2 feet, carried a load of 4,083 pounds without injury. A similar modillion 5½ inches high, 6 inches wide, with a projection of 14 inches, broke under 2,650 pounds. Another bracket from the same mold, inserted in the same hole, sustained 2,400 pounds without breaking.

396. PROTECTION.—The carpenter's specifications should provide for boxing all molded and ornamental work with rough

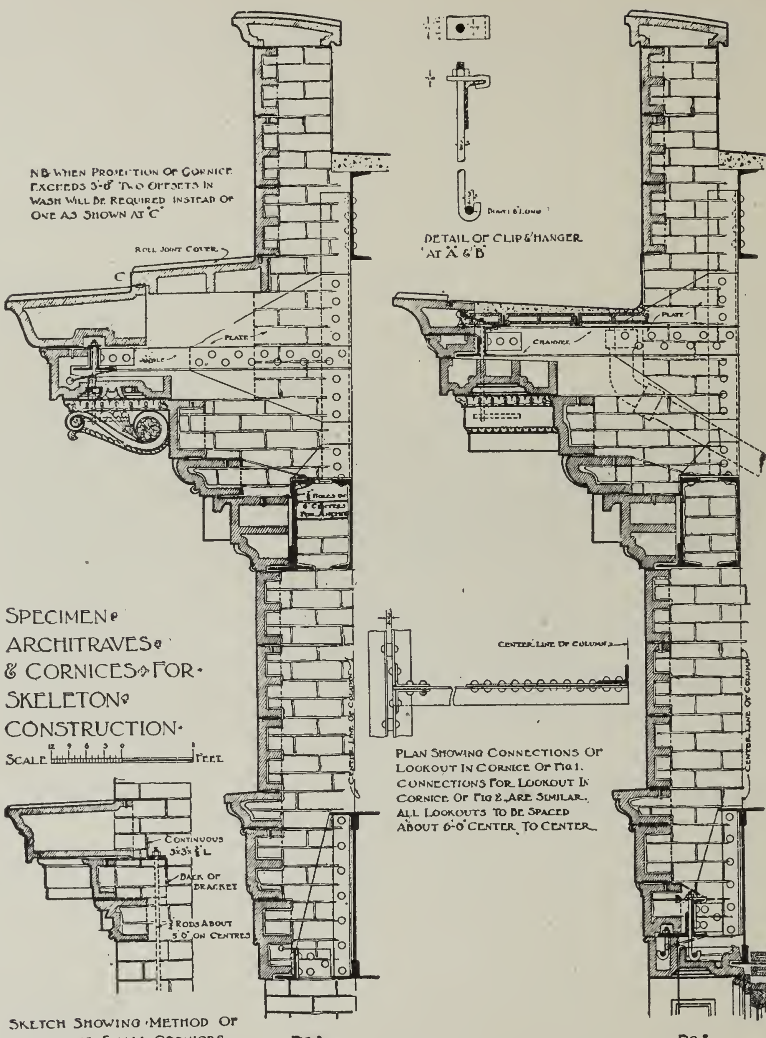


Fig. 258. Typical Terra-cotta Cornices for Skeleton Construction.

pine boards to guard against damage during construction. Hemlock is unsuited for this purpose, as it is liable to stain the terra-cotta.

397. EXAMPLES OF TERRA-COTTA CONSTRUCTION. —*Cornices.*—Where buildings are trimmed with terra-cotta the cornice is generally made of the same material. For cornices having considerable projection terra-cotta possesses the advantages over

stone of being much lighter, thus permitting a lighter wall and steel construction, and in all cases it is much less expensive. With stone cornices it is necessary that the various pieces be of sufficient depth to balance on the wall. With terra-cotta cornices, however, this is not customary, the various pieces being made to build into the wall from four to twelve inches, or to be supported by iron work. Generally small angle-irons placed back to back and forming a T, but with a space of one inch between them, are used as outlookers to support the soffit course, and also the modillions, which are held up by hangers which catch a pipe extending the full length of a modillion. Where the projection is great enough to overbalance the weight of the masonry on the built-in end, allowing for the weight of snow on the projection, the inner end of the outlooker must be anchored down by a continuous channel or angle, bolted every few feet to the wall by rods, carried down into the wall until the weight of the masonry above the anchor is ample to counteract the leverage of the projection. Unless the wall is very heavy, it is also advisable to anchor the top of the wall to the roof chimneys to prevent its inclining outward. An illustration of this method of construction is given in Fig. 257, which shows sections, plan and elevation of a cornice built by the Atlantic Terra-cotta Company for the Church of Christ Scientist, Los Angeles, California.

Fig. 258* shows some examples of typical terra-cotta cornice construction used with skeleton-frame buildings, with all details.

These sections are of very recent and up-to-date work, and may be taken as models of good economical construction in terra-cotta where a heavy projection is required. When a cornice is supported by iron work, the method of anchoring must be decided before the work is made, as provision must be made in the blocks for inserting the beams or anchors; and a copy of the steel drawings should be furnished the manufacturer to enable him to get out his part of the work correctly. All of this steel work should be so designed that it is adjustable, as the inaccuracies of building are such that if the positions of the iron are fixed they will sometimes be at variance with the provisions for the terra-cotta.

Pediments.—Fig. 259* shows terra-cotta pediment and cornice detail construction, with entire entablature, and with plan of soffit, elevations and sections of returns and corner supports.

* Courtesy of the Northwestern Terra-cotta Company, Chicago.

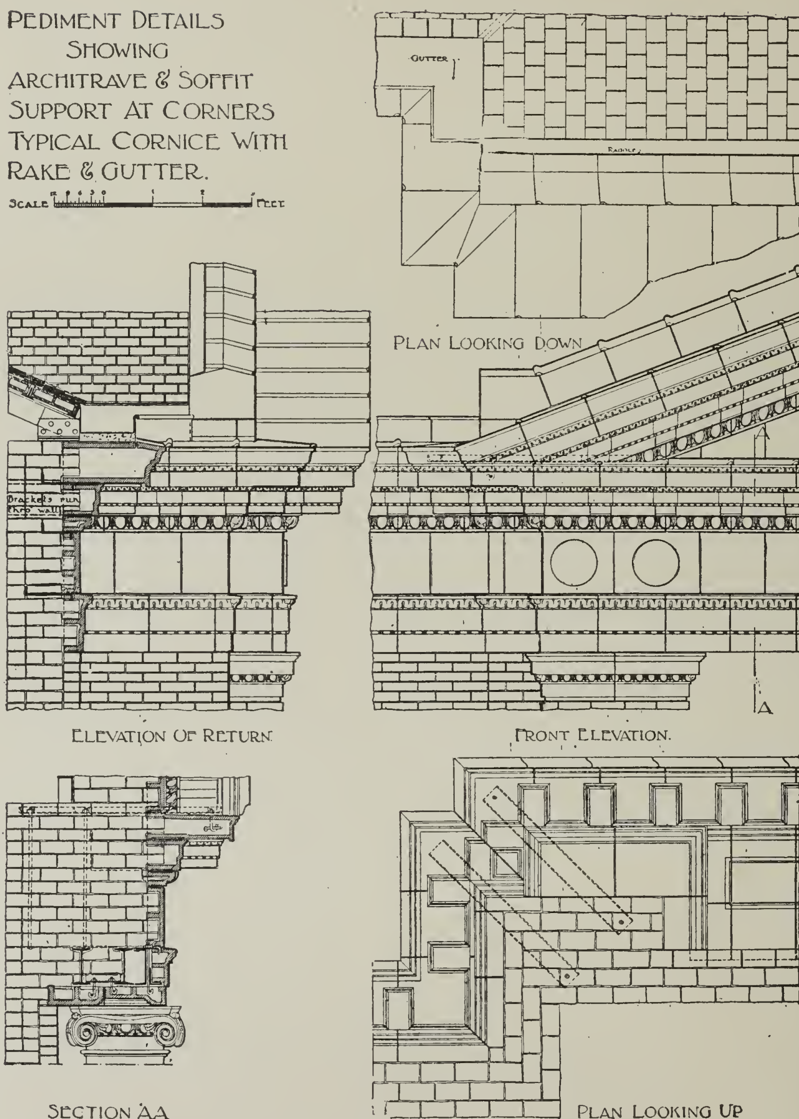


Fig. 259.—Terra-cotta Pediments and Cornice Details.

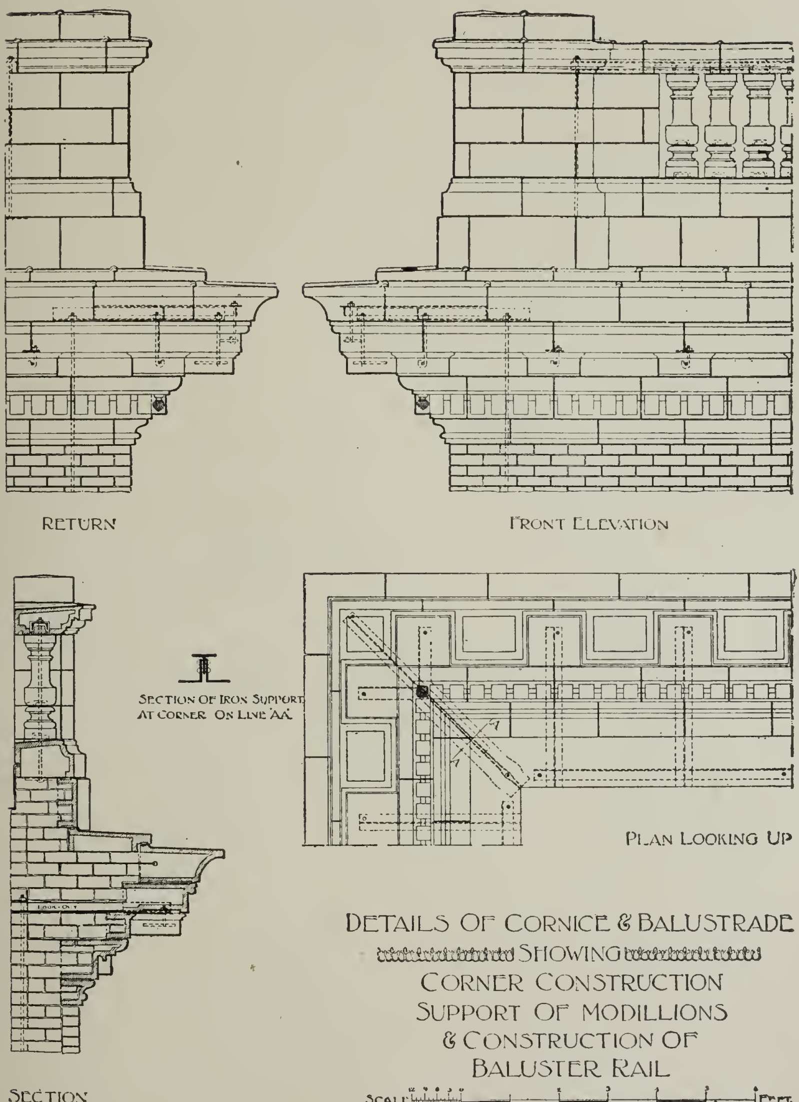


Fig. 260.—Terra-cotta Balustrade and Cornice Details.

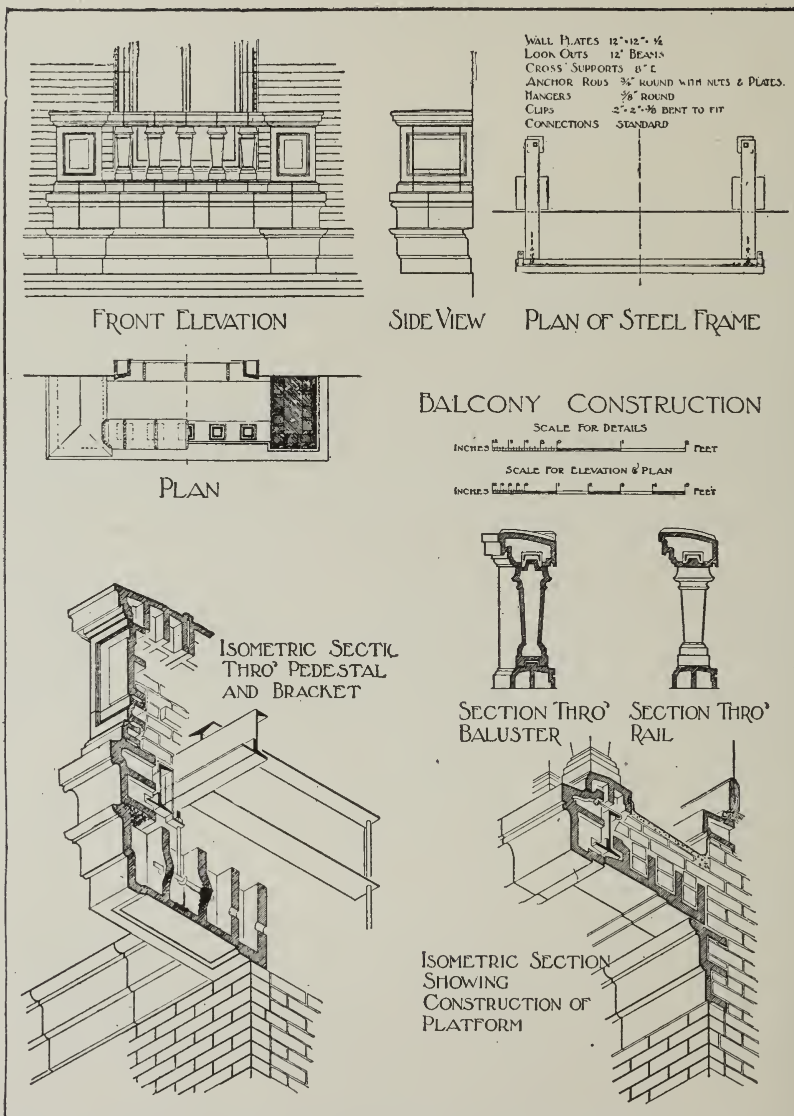


Fig. 261.—Terra-cotta Balcony Details.

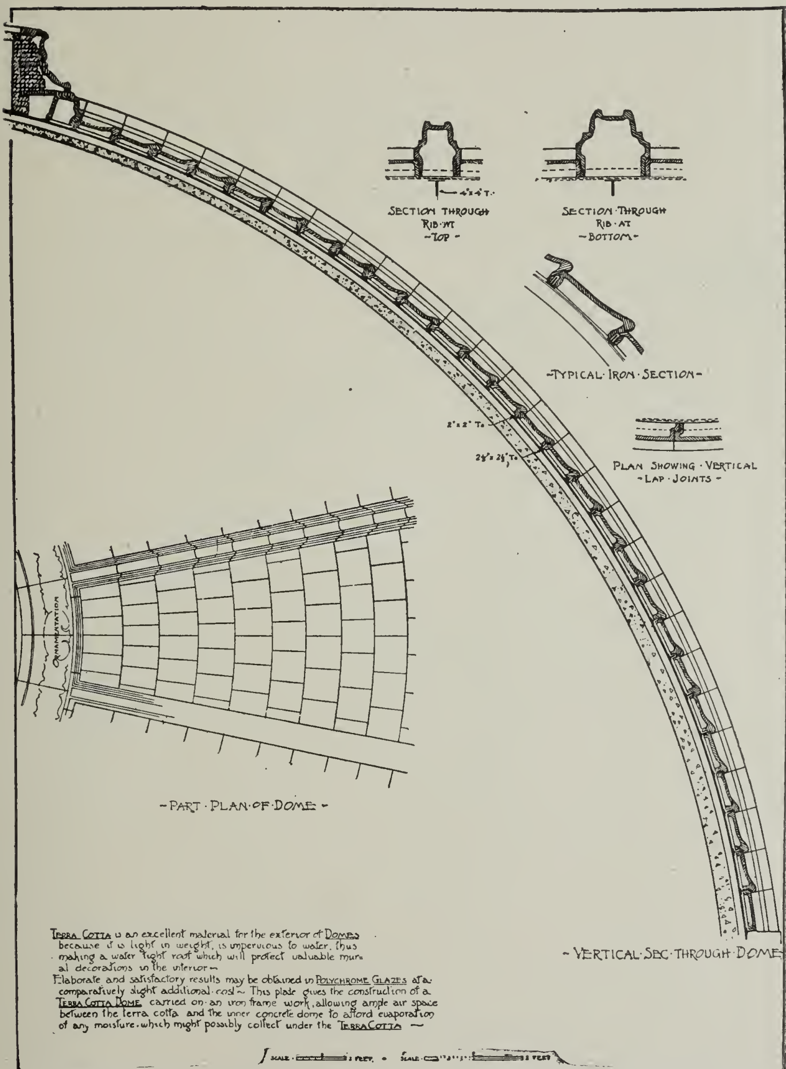


Fig. 262.—Terra-cotta Dome, First Church of Christ Scientist, Boston.

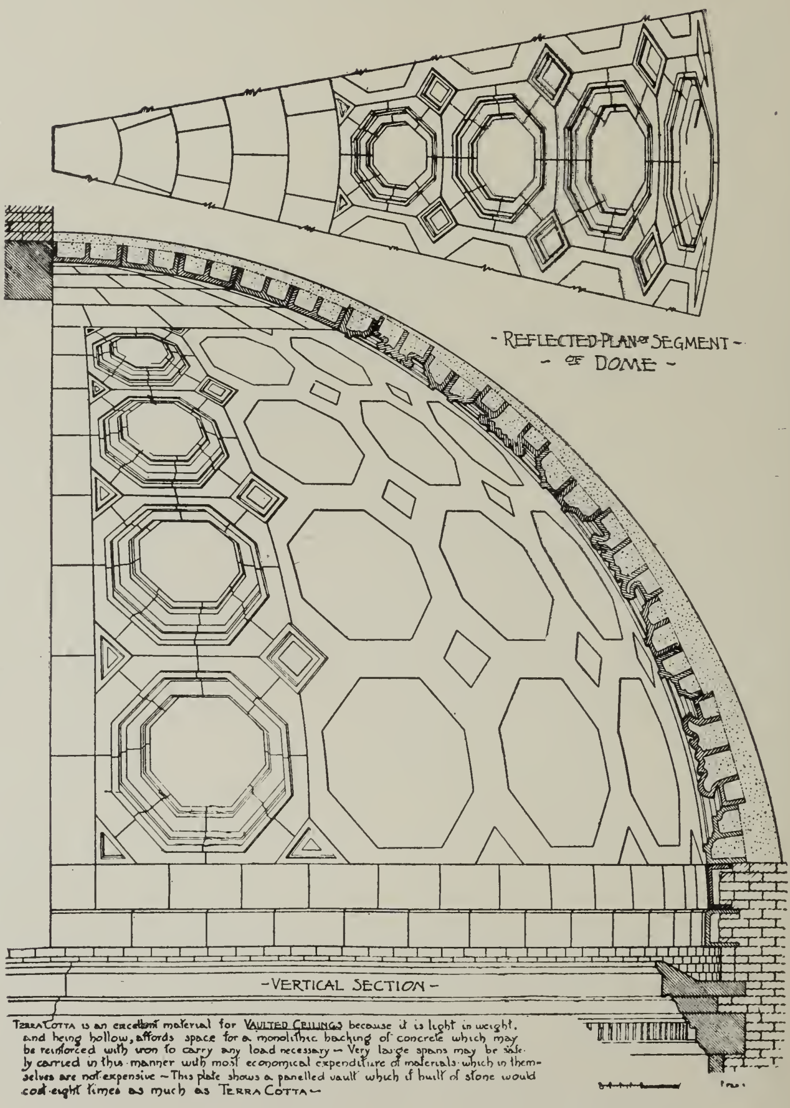


Fig. 263.—Terra-cotta Vaulted Ceiling, Union Station, Washington, D. C.

Balustrades.—Fig. 260* shows terra-cotta balustrade and cornice detail construction, with modillion and corner supports, plan of cornice soffit, return, section, detail construction of balustrade posts or pedestals, rails, balusters, etc.

Balconies.—Fig. 261* shows terra-cotta balcony detail construction, with plan of the steel-supporting frame, sections through rails and balusters, isometric perspectives and sections through the platform, pedestals, brackets and steel supports.

Domes.—Fig. 262† shows the construction of the domes for the First Church of Christ Scientist in Boston, Mass., Charles Brigham, architect.

Terra-cotta is an excellent material for the exterior of domes, because it is light in weight; and being impervious to water, makes a water-tight roof which will protect valuable mural decorations in the interior. Elaborate and satisfactory results may be obtained in polychrome glazes at a comparatively slight additional cost. This plate shows the construction of a terra-cotta dome, carried on an iron framework, allowing ample air-space between the terra-cotta and the inner concrete dome to allow evaporation of any moisture which might possibly collect under the terra-cotta.

Vaulted Ceilings.—Fig. 263† shows the construction of one of the vaulted ceilings built in the Union Station at Washington, D. C., D. H. Burnham & Company, architects.

For vaulted ceilings also terra-cotta is an excellent material, not only because of its light weight, but because, being hollow, it affords space for a monolithic backing of concrete, which may be reinforced with steel to carry any load necessary. Very large spans may be safely carried in this manner with an economical expenditure of materials which in themselves are not expensive.

The figure shows a panelled vault which, if built of stone, and with the same design and ornamentation, would cost many times as much.

Terra-cotta Facing for Reinforced Concrete.—The method of attaching terra-cotta facing to reinforced concrete walls is shown in Fig. 264.† The anchors are built into the forms before the concrete is poured. When the concrete is hard the position of these anchors is fixed; therefore there must be some method of adjustment in attaching them to the terra-cotta. This is arranged by

* Courtesy of the Northwestern Terra-cotta Company, Chicago.
† Courtesy of the Atlantic Terra-cotta Company, New York.

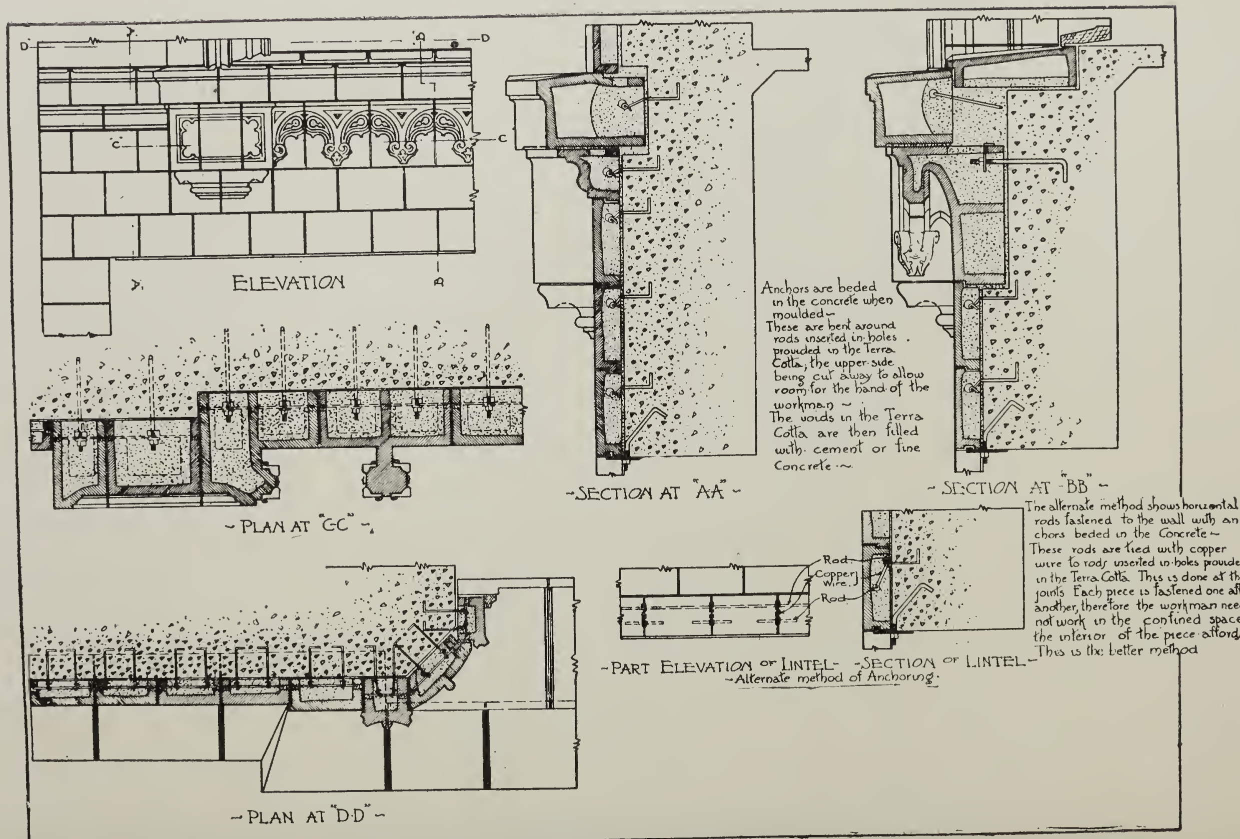


Fig. 264.—Terra-cotta Facing for Reinforced Concrete Walls.

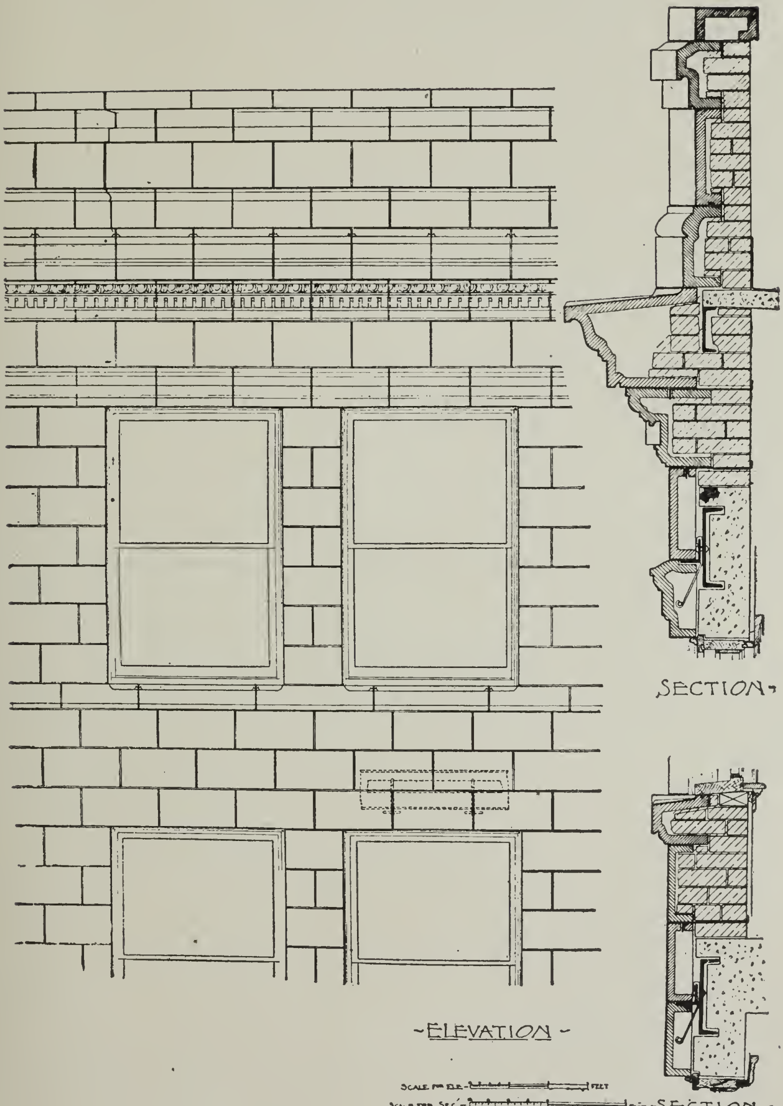


Fig. 265.—Terra-cotta Facing for Light-courts.

placing rods in holes provided in the terra-cotta and bending the anchors around these rods wherever they come in contact. Another method is to place continuous rods against the walls and bend the anchors around them, wrapping copper wire around these rods, and tying them to the rod in the terra-cotta. The concrete may be molded so as to form shelves for the support of projecting cornices, and pipes may be placed in the walls as anchor holes through which to pass bolts or rods where necessary. The terra-cotta facing after being attached should have the voids at the back filled with mortar or cement.

Light-courts.—Fig. 265* shows a treatment for the light-courts of large office-buildings or apartment-houses. The great advantages of terra-cotta for such purposes are now recognized. It absorbs no dirt from the atmosphere, washing clean after a storm. The enduring white color reflects the light, adding materially to the amount obtained. The figure shows a conventional treatment of ashlar facing with sills and cornice, showing proper methods of construction and anchoring.

398. FIRE-RESISTANCE OF TERRA-COTTA.—Architectural terra-cotta, being made of clay, and burned to a high temperature, offers the same resistance to fire as terra-cotta fire-proofing. This fact was demonstrated during the Baltimore and San Francisco fires, where buildings constructed of this material showed great resistance to the disastrous conflagration. In the case of the Union Trust Building in Baltimore, constructed with architectural terra-cotta exterior wall-facing and terra-cotta fire-proofing interior, although all inflammable materials in the building were consumed, these building materials protected the constructional steel to such an extent that while the architectural terra-cotta was badly stained by smoke and was renewed on this account, the steel frame was virtually unharmed.

In some cases where the buildings were constructed of stone it was necessary to take down the steel frames which were badly warped and weakened.

The Fairmont Hotel, in San Francisco, is another instance demonstrating the fire-resisting qualities of terra-cotta. Although in the middle of the burned area, most of the damage to the building was caused by the earthquake and by the smoke stains on the terra-cotta.

* Courtesy of the Atlantic Terra-cotta Company, New York.

CHAPTER IX.

Fire-proofing of Buildings.

I. INTRODUCTION.

399. GENERAL CONSIDERATIONS.—Most of the materials employed for protecting the structural portions of buildings from fire and heat, and for filling between the floor beams and rafters, are of earthy composition and come within the province of the mason or plasterer.

The *constructive* fire-proof materials, that is, those which have to support any weight, most extensively used in this country are dense hollow tiles, porous terra-cotta tiles or blocks and various concrete compositions generally combined with steel in the shape of small bars, wires or netting. These materials are used in different forms and in different ways, and many of them are covered by patents controlled by large manufacturing corporations. Some of these manufacturing corporations used to take contracts to furnish all the fire-proofing material required in a building and to put it in place, leaving the building ready for the plasterer and carpenter. They now generally confine their business to manufacturing the material. There are, however, in the case of reinforced concrete construction, fire-proofing companies that estimate from the architect's drawings and give a lump-sum price for the total reinforcement of a building, set in place in the forms; and in the case of tile or terra-cotta fire-proofing and fire-proof construction, companies that are prepared to execute entire fire-proofing contracts.

The kind of material and method of fire-proofing that is to be employed should be decided upon before the framing plans are made, as the details of framing differ with different systems. Some systems also effect a sufficient saving in dead weight to enable lighter beams and columns to be used than are required with heavier systems.

If competitive bids are desired to assist in determining the kind of fire-proofing to be employed, they can often be obtained before the

plans are completed, the position of the columns determining the spans and widths of arches.

In the case of terra-cotta tile floor arch construction, if it is decided to use either porous or dense tile arches, it is not absolutely necessary to specify any particular make of tile, the specifications being written so that any tile which fulfils the conditions therein contained may be used.

The subject of fire-proof construction has received a great deal of attention during the past few years, and the increased demand for a safe and economical system of fire-proofing has led to the introduction of many systems, some of which, however, may be said to be still in the experimental stage. A great many tests have been made of the various physical properties of different materials used in connection with the fire-proofing of buildings. As it is not the purpose of this book to enter extensively into the subject of the strength of materials, but rather to describe methods of construction, we shall here undertake to describe only those methods of fire-proofing in vogue in this country, referring the reader to the author's "Pocket-Book," and to records of various tests published in the different journals and government publications for more complete data.

A careful comparison of the cost per cubic foot of a large number of buildings estimated for both fire-proof and ordinary construction seems to indicate that the cost of the fire-proof construction is from 9 to 13 per cent greater than that of the wooden-joist construction; and that, in the case of such buildings as stores and warehouses, as small an amount as 5 per cent will cover the difference in cost.*

400. VARIOUS DEFINITIONS OF FIRE-PROOFING.—The building codes of the different cities carefully define what is meant by the term "fire-proof construction." They differ in wording and also in some details of requirements, but there is a constantly increasing tendency toward uniformity both in the matter and in the form of these laws and ordinances.

The codes of the smaller cities are in many cases based upon, or follow closely, those of the largest cities and it will be sufficient to quote from the laws of the three largest cities, New York, Chicago and Philadelphia.

* For cost of buildings per cubic foot and per square foot, etc., see the "Architect's and Builder's Pocket-Book," by Frank E. Kidder. Part III.

The New York Definition of Fire-proof Construction.—The Building Code of the City of New York requires that buildings which are to be classed as "fire-proof" shall be "constructed with walls of brick, stone, Portland cement concrete, iron or steel, in which wood beams or lintels shall not be placed, and in which the floors and roof shall be of materials provided for in Section 106 of this Code. The stairs and staircase landings shall be built entirely of brick, stone, Portland cement concrete, iron or steel. No woodwork or other inflammable material shall be used in any of the partitions, floorings or ceilings in any such fire-proof buildings, excepting, however, that when the height of the building does not exceed twelve stories nor more than one hundred and fifty feet, the doors and windows and their frames, the trims, the casings, the interior finish (when filled solid at the back with fire-proof material), and the floor boards and sleepers directly thereunder, may be of wood, but the space between the sleepers shall be solidly filled with fire-proof materials and extend up to the under side of the floor boards.

"When the height of a fire-proof building exceeds twelve stories, or more than one hundred and fifty feet, the floor surface shall be of stone, cement, rock or asphalt, tiling or similar incombustible material, or the sleepers and floors may be of wood treated by some process, approved by the Board of Buildings, to render the same fire-proof. All outside window frames and sash shall be of metal, or wood covered with metal. The inside window frames and sash, doors, trim and other interior finish may be of wood covered with metal, or wood treated by some process approved by the Board of Buildings to render the same fire-proof.

"All hall partitions or permanent partitions between rooms in fire-proof buildings shall be built of fire-proof material and shall not be started on wood sills, nor on wood floor boards, but be built upon the fire-proof construction of the floor and extend to the fire-proof beam filling above. The tops of all door and window openings in such partitions shall be at least twelve inches below the ceiling line."

The Section 106 referred to above has reference to the subject of "fire-proof floors," and the Code permits them to be constructed of any materials successfully standing the tests prescribed, such as brick, tile, cement concrete, etc.

The Chicago Definition of Fire-proof Construction.—In the article on "Fire-proof Construction" in the "Revised Municipal

Code Governing the Erection of Buildings," the following definition is given: "The term fire-proof construction shall apply to all buildings in which all parts that carry weights or resist strains, and also all exterior walls and all interior walls and all interior partitions and all stairways and all elevator enclosures are made entirely of incombustible material, and in which all metallic structural members are protected against the effects of fire by coverings of a material which shall be entirely incombustible, and a slow heat conductor, and hereinafter termed 'fire-proofing material.' Reinforced concrete as defined in this ordinance shall be considered fire-proof construction.

"The materials which shall be considered as filling the conditions of fire-proof covering are: first, burnt brick; second, tiles of burnt clay; third, approved cement concrete; fourth, terra-cotta; fifth, approved cinder concrete."

The Philadelphia Definition of Fire-proof Construction.—The laws and ordinances relating to the Bureau of Building Inspection of Philadelphia contain the following requirements and the definition of fire-proof construction:

"Where the inclosing or division walls of a building are wholly or in part supported on iron or steel beams, girders and columns, such beams, girders and columns shall be protected against the external changes of the atmosphere and against fire by a covering of brick, terra-cotta, fire-clay, tile, or other approved fire-proofing, completely enveloping said structural members of iron or steel. Said fire-proofing around outside columns and beams, if of brick, shall not be less than eight (8) inches; if of hollow tile, shall not be less than six (6) inches thick; and there shall be at least two sets of air-spaces between the iron and steel members and the outside of the hollow tile covering. In all cases the brick or hollow tile shall be bedded in cement mortar close up to the iron or steel members, and all joints shall be made full and solid.

"No building shall be deemed a fire-proof building unless, in addition to the above required covering of the iron or steel members, all the interior columns, beams and girders be enveloped in such fire-resisting materials as shall be approved by the Bureau of Building Inspection."

401. CONDITIONS LIMITING THE HEIGHTS AND AREAS OF NON-FIRE-PROOF BUILDINGS.—On account of the difficulties met with in dealing with fires in high buildings and

in buildings of large area and few interior division walls, the building laws of cities place limitations upon non-fire-proof structures in regard to both their height and their floor area.

The following table gives the limiting heights for non-fire-proof buildings for some of the larger cities of the United States:

TABLE XXVIII.

LIMITING HEIGHTS FOR NON-FIRE-PROOF BUILDINGS.

City	All Buildings	Hotels	Schools	Hospitals and Asylums	Residence Buildings
Buffalo, N. Y.	72 ft.				
New York, N. Y.	75 ft.	35 ft.	35 ft.	35 ft.	
Kansas City, Mo.	75 ft.				
St. Louis, Mo.	75 ft.	....	2 stories above basement	2 stories above basement	4 stories and basement
Boston, Mass.	75 ft.	....	....	....	65 ft.
Washington, D. C.	75 ft.	60 ft.	....	....	60 ft.
New Haven, Ct.	75 ft.	60 ft.	60 ft.	45 ft.	
Denver, Col.	80 ft.	....	3 stories	3 stories	
San Francisco, Cal.	84 ft.				3 stories
Seattle, Wash.	85 ft.	3 stories	....	....	
Omaha, Neb.	90 ft.				
Chicago, Ill.	100 ft.	....	3 stories	2 stories	5 stories and basement
Baltimore, Md.	100 ft.				
Milwaukee, Wis.	100 ft.				
Cleveland, O.	100 ft.				
New Orleans, La.	....	52 ft.	....	52 ft.	
Newark, N. J.	....	....	....	....	3 stories
Philadelphia, Pa.	....	....	....	....	4 stories

The following are the limiting areas for non-fire-proof buildings, taken from the building laws of the five largest cities:

LIMITING AREAS FOR NON-FIRE-PROOF BUILDINGS.

Chicago	8,000	square feet on an interior lot.
	12,500	square feet on a corner.
	22,000	square feet when facing three streets.
New York	9,000	square feet if of ordinary wood-joist construction.
	12,000	square feet if of slow-burning construction.
Philadelphia	5,000	square feet if of ordinary wood-joist construction.
	15,000	square feet if of slow-burning construction.
St. Louis	7,500	square feet.
Boston	5,000	square feet.

402. DIVISIONS OF THE SUBJECT.—The subject of this chapter, "Fire-proofing of Buildings," may be conveniently divided into two principal divisions, viz., Fire-proofing Materials and Fire-proof Construction.

2. FIRE-PROOF MATERIALS.

403. GENERAL CONSIDERATIONS.—Various materials have been introduced at different times for the purpose of making buildings fire-proof. Experience has shown, however, that the only practical method of producing a really fire-proof building is by using only incombustible materials for its structural parts and protecting all structural metalwork with some fire, water and heat-resisting material. The ideal fire-proof building would undoubtedly be one that was constructed entirely of brickwork and terra-cotta or of heavy approved cement concrete, with brick, concrete or tile floors or roofs, built in the form of vaults sprung from brick piers and without the employment of structural metalwork. Such a building, if properly designed and built, would withstand the combined action of all the elements for centuries. Modern commercial requirements, however, demand that the vertical supports shall be as small and as far apart as possible, and that the floors shall be thin and have level ceilings; and these can be obtained only by the use of metalwork.

The materials that have been found to successfully answer the purposes of modern fire-proofing are confined to burned brick, tiles of burned clay, terra-cotta, approved cement concrete and cinder concrete.

While considering the materials adapted to fire-proofing and to fire-proof construction, we may also briefly mention some, which, while they are frequently used in very important buildings, will not successfully stand the action of severe heat.

404. STONE.—Granite, sandstone, limestone, marble and building-stones in general are unsatisfactory materials either for fire-proofing or for exterior ornamentation when exposed to fire. They all scale and spall and are often so badly damaged that they require entire renewal. In the recent large conflagrations they were found to be unsuitable for bases, columns, lintels, caps, etc., or for supporting loads in locations above ground where they were exposed to great heat.

Granite tends to fly to pieces or to explode when exposed to flames. It is generally the least refractory material among the stones in case of fire, with the exception of the limestones and marbles, which frequently meet with total destruction from the heat of an average fire. In the San Francisco fire the sandstone used

for the façades of many of the buildings generally developed better fire-resistance than the granite, but was still in many cases badly disfigured by moderate heat. The sandstones which stand fire with the least injury are those having a compact and fine-grained homogeneous structure; but even these are seriously injured in the intense heat of great conflagrations.

405. BRICK.—As a fire-proof or fire-resisting material, burned brick is vastly superior to stone. As a matter of fact, recent severe conflagrations, like the San Francisco, Baltimore, Rochester and Toronto fires, proved that for outside wall construction, brick, as a fire-protecting material, is superior to any other used.

It is important to bear in mind, however, the following facts learned or confirmed by recent experiences:

(1) Thin brick walls are more severely affected by heat than thick walls.

(2) Soft or underburned bricks are more severely affected by heat than hard-burned bricks.

(3) Good quality common brickwork will stand exposure to ordinary fires for a long time.

(4) Good quality common brickwork, when subjected to the long-continued severe heat of a conflagration, tends to expand on the heated side, often endangering the stability of a wall, cracking the bricks and sometimes even partially melting them.

(5) Brick walls which are lined with hollow bricks or porous furring tiles on the sides subjected to great heat will stand exposure to fire without injury for a longer time than similar walls unlined.

406. TILING AND TERRA-COTTA.—Burned clay has numerous applications in incombustible building construction. Tiling and terra-cotta may be considered under two subdivisions:

(1) Structural Tiling and Terra-cotta,

(2) Ornamental or Architectural Terra-cotta.

407. STRUCTURAL TILING AND TERRA-COTTA.—For the construction of floors, partitions and light walls, and for the casing of columns, beams and girders, the clay is molded into hollow tiles or blocks of three general kinds:

(*a.*) Dense tiling.

(*b.*) Porous tiling.

(*c.*) Semi-porous tiling.

Dense tiling is also sometimes called "fire-clay tile," "hollow

pottery," "hard tile," "terra-cotta," etc.; and porous tiling is sometimes called "porous terra-cotta," "terra-cotta lumber," "cellular pottery," "soft tiling," etc.

Dense and semi-porous material is used for floor arches; dense, semi-porous and porous for partitions and furring; semi-porous and porous for column and girder covering and for roof blocks.

The terms "hollow tiling" and "fire-proof tiling" are used when they are referred to in a general way.

(*a.*) *Dense Tiling.*—This is generally made of fire-clay, combined with potters'-clay, plastic clays or tough-brick clays, molded by dies into the various hollow forms required for commercial use. The clay is subjected during its manufacture to a high pressure while in a moist or damp state, which gives the finished material great crushing strength. After drying, the tiles are burned like terra-cotta in a kiln, at a temperature of from 2000° to 2500° Fahr.

Dense tiling in solid blocks is unquestionably stronger than porous tiling, although more brittle. When made from fire-clay it is undoubtedly a thoroughly fire-proof and non-conducting material, but it will not stand the combined effects of fire and cold water as well as the porous tiling. In outer walls, exposed to the weather and required to be light, dense tiling is very desirable. Some manufacturers furnish it with a semi-glazed surface for outer walls of buildings. For such use it has great durability and effectually stops moisture.

In using dense tiling for fire-proof filling, care should be taken that the tiles are free from cracks, sound and hard-burned.

(*b.*) *Porous Tiling.*—This is formed by mixing sawdust with pure clay and submitting it to an intense heat, by the action of which the sawdust is destroyed, leaving the material light and porous like pumice-stone. The toughness of the clay used determines the proportion of sawdust, which varies from 25 to 35 per cent. When properly made it will not crack nor break from unequal heating nor from being suddenly cooled by water when in a heated condition. It can also be cut with a saw or edge-tools, and nails and screws can easily be driven into it to secure interior finish, slates, tiles, etc.

For the successful resistance of heat, and as a non-conductor, the author believes there is no building material equal to it, especially when used in thin sections. To develop the above properties to the fullest extent, the blocks should be manufactured from tough

plastic clays mixed with a small percentage of fire-clay. This admixture of fire-clay is desirable but not essential.

Porous tiles, when properly made and burned, should be compact, tough and hard and should ring when struck with metal. Poorly mixed pressed or burned tiles, or tiles from short or sandy clays, present a ragged, soft and crumbly appearance, and are not desirable.

Porous tiles for floor construction, or for construction carrying considerable weight, should be made with not less than 1-inch shells; and the webs or partitions dividing the spaces should be from ¾ to ⅞ of an inch thick, according to the size of the hollows.

Porous tiles possess the advantage over hard tiles of being light, tough and elastic, while dense tiles are hard and brittle.

(*c.*) *Semi-porous Tiling.*—This is a sort of mean between the other two kinds of structural tiling. Opinions differ somewhat as to the exact ratio that its general resisting properties bear to those of the others; but some good authorities believe that it is as efficient as the standard makes of porous terra-cotta in resisting fire.

In the process of grinding, about 20 per cent of ground coal is mixed with the clay, which, while aiding in the burning of the material, makes it also lighter and more or less porous. It is undoubtedly a better fire-resistant than dense tiling.*

408. ORNAMENTAL OR ARCHITECTURAL TERRA-COTTA.—Among the refractory materials used in the façades of buildings, ornamental terra-cotta is one which ranks high. While it did not stand the intense heat of recent severe conflagrations as well as did some pressed silica bricks and terra-cotta bricks made in the size of common bricks, and while some which was made with thin shells and webs failed in many instances, that which was made and erected with care, and which had shells or wells 2 inches or more in thickness, gave very satisfactory results.

It is considered the best material for elaborate or projecting ornamentation of buildings intended to be fire-proof, and a glazed surface adds still more to its efficiency. The reconstruction necessary after subjection to great heat followed immediately by water has been found to be very small in amount when compared with that required for other materials, with the single exception of fire-brick.

* For notes on "The Strength of Terra-cotta," see the "Architect's and Builder's Pocket-Book," by F. E. Kidder.

409. MORTAR.—In all building construction in which the principal materials used consist of brick, stone or terra-cotta, whether the character of the construction be fire-proof or non-fire-proof, the material, mortar, enters to bind together the several units.

In addition to its binding properties, and its properties of damp-resistance, general strength and endurance, its fire-resistance may be considered.

Lime mortar acts fairly well in good brick walls and piers in resisting heat, but it is the general opinion that the best cement mortar gives superior results.

410. PLASTER.—When lime plaster has been applied to wire lath and subjected to a high temperature, as in the case of actual fires in buildings, it has been found to stand in many cases without serious injury; but some of the plaster of the same walls has been washed away in places by streams of water from the fire hose.

Patent plasters or hard wall-plasters seem to resist great heat, and also great heat followed by the sudden application of cold water, as effectively as do the lime plasters, when they are applied to metal lath or brickwork.

There has been considerable controversy regarding the question of the fire-resisting properties of various mortars and plasters. Up to a certain degree of temperature, varying with the composition and mixture of mortar or plaster used, and by no means reaching the maximum temperatures of conflagrations, all such compositions stand fairly well. Beyond that each one is more or less seriously affected, and some fail entirely.

Asbestic Plaster.—This is a plaster made by mixing with lime-putty, freshly slacked, a certain proportion of "asbestic," a composition mined in Canada and containing a large proportion of asbestos.

It seems to have successfully withstood severe tests of fire and water, the plaster, in most cases, remaining in place, uncracked and unbroken.

It has been used in some important buildings, notably the Appraisers' warehouse in New York City, where it was applied to the concrete or terra-cotta surfaces of the walls, ceilings and columns to a thickness of from ½ to ¾ of an inch.

The recommendations for this plaster are its toughness, elasticity, property of receiving nails without cracking, light weight of about

half that of average cement mortar, fire and water-resistance, and non-tendency to discoloration from percolating water, acids, etc. The greatest objection to this plaster is its slow-drying property.

411. PLASTER-OF-PARIS COMPOSITIONS.—In France a composition of plaster of Paris and broken bricks, chips, etc., has been used for generations for forming ceilings between beams, and its durability is there unquestioned. A composition consisting of 5 parts by weight of plaster of Paris and 1 part of wood shavings, mixed with sufficient water to bring the mass to the consistency of a thin paste, was introduced into this country in connection with the formerly used "Metropolitan System" of floor construction. It was claimed that this material is a remarkable non-conductor of heat, and that a moderate thickness of it prevents the passage of nearly all warmth.

This composition is much lighter in weight than ordinary cement concrete.

When subjected to a high temperature these compositions have a tendency to soften on their surfaces, and to wash away to a greater or less depth when a stream of water is thrown on them.

412. CONCRETE.—In connection with the discussion of the fire-resisting properties of concrete, the reader is referred also to the articles relating to it, in Chapter X, "Concrete and Reinforced Concrete Construction."

Stone Concrete.—The following is a brief summary of conclusions reached regarding the action of stone concrete under the influence of heat:

(1) Stone concrete is a poor conductor, allowing its heated surface to expand, and the rest of its body to remain cold, thus causing cracks or warping or both together.

(2) Both the strength and texture are apt to be affected by great heat, with an accompanying disintegration to about one inch in depth, and a frequent spalling off of the surface.

(3) The surface is generally washed away to the depth of the part injuriously affected, when a powerful stream of water is applied after the heat.

(4) Deleterious effects usually vary with the kind of stone used in the aggregate. Limestone, under the action of heat, is calcined, and under the action of the water is often destroyed. Granite and gravel tend to spall, because their coefficient of expansion is differ-

ent from that of the remainder of the concrete body and of the concrete as a whole. Trap-rock, on account of both its strength and its fire-resisting properties, is considered the best of the stones for use in the aggregates.

(5) Concretes partially injured by fire may set again and become hard, if there is a gradual cooling off of the surface, and if no water is applied; but this result cannot always be relied upon.

Slag Concrete.—Some very satisfactory results have been obtained from the use of blast-furnace slags in the aggregates of concrete, as far as both the strength and the resistance to fire is concerned.

Slag for concrete work should be crushed slag, the size of the pieces being about the same as those usually specified for crushed stone, and the material being free from sulphur or other injurious agents, and hard and not spongy.

Cinder Concrete.—Observations made on the effects of great heat upon concretes have led to the conclusion that cinder concrete is an excellent fire-resisting material. The objections to its use is its non-uniformity and consequent variable and often doubtful strength.

When it is used the cinders should be good quality, clean steam cinders, free from unburned particles of coal, or at least containing not more than 15 per cent of such coal; and it should be ground by machinery before mixing.

On account of its variable strength, a high factor of safety is generally used in the case of cinder concrete, one-tenth the breaking load being customary in many cities when it is used in floor construction. In the various building codes the unit stresses allowed for reinforced concrete work with cinder concrete are much lower than those for slag concrete, and very much lower than those for stone or gravel concrete for flexure-compression, shear and adhesion and also for direct compression.

Care should always be taken to guard against the tendency toward the corrosion of steel encased in cinder concrete.

413. CAST-IRON.—Buildings in which unprotected iron or steel columns are used cannot be rated as fire-proof buildings. While there are cases in which the character and location of a building and the character of its contents are such that cast-iron columns, unprotected, would probably safely withstand any heat to which they would probably be exposed, it is nevertheless always best to protect such columns with some approved covering.

The heat usually generated by the average contents of most mercantile buildings during a severe fire is estimated to be as high as 2000° Fahr. and higher. It is known that unprotected cast-iron, subjected to temperatures up to from 1300° to 1500°, carrying heavy loads, and treated with streams of cold water when red-hot, will stand practically uninjured. After the temperatures pass these points, the columns begin to fail. Consequently in very hot fires in buildings, cast-iron columns, when unprotected, are pretty sure to fail by breaking or bending.

414. WROUGHT-IRON AND STEEL.—Elaborate fire tests have been made upon wrought-iron, steel and cast-iron columns in order to determine the effect of great heat with succeeding cold water upon them, and these have been naturally supplemented by the accidental tests of recent great conflagrations.

Unprotected steel columns bearing heavy loads usually begin to fail at a temperature of about 1100° Fahr., and with varying higher temperatures they expand and soften sufficiently to bend and twist. They should therefore not be employed, when unprotected, in fire-proof construction; and this was abundantly confirmed in many instances by the Baltimore and San Francisco fires.

415. MISCELLANEOUS FIRE-PROOF MATERIALS.—There are other fire-proof and fire-resisting materials in addition to those that have been mentioned, such as wire-glass, fire-proof wood, fire-proof paint, etc.; but as they do not belong to masons' work, they will not be considered here. For a discussion of their properties and uses the reader is referred to the "Architect's and Builder's Pocket-Book," by Frank E. Kidder, in the chapter on "Fire-proofing of Buildings."

3. CONSTRUCTION.

1. COLUMN PROTECTION.

416. GENERAL CONSIDERATIONS.—The protection of the columns, especially in high buildings, should be considered the most important part of the fire-proofing. While the thoroughness of such protection is constantly approaching a more nearly ideal stage, in too many instances in the past it has been neglected, often to the point of danger. The columns and girders form the vital parts of the skeleton frame, and the failure of a column usually causes failures in more of the other structural units than does the failure of any other one part.

The character of the floor system chosen usually decides the character of the materials and the form of column-protection. If the floor system is one of concrete, this material is usually adopted to cover the columns and girders; while if the floor system is one of hollow tile, this material is usually employed for column and girder-protection.

Careful tests made upon full-sized unprotected steel and cast-iron columns show that steel columns fail at an average temperature of 1150° Fahr., and that cast-iron columns fail at an average temperature of 1300° Fahr., the average duration of such temperatures being about 50 minutes.

The commonest and cheapest method of fire-proofing interior columns was formerly by the use of shells of dense terra-cotta surrounding the columns, the separate tiles being usually clamped or hooked together, but not to the metalwork. This method did not prove altogether successful.

"The use of dense tiles is only to be recommended when such tiles are hollow, with a proper air-space around the metal column; and even then experience seems to show that the hard tiles are in no way as satisfactory under great heat as the more porous kinds."*

It is important to know as much as possible regarding the relative value of different materials used as protective coverings, and with this end in view, careful tests have been made of the conductivity of these materials.

The results of these tests, which were made by the Bureau of Buildings of New York City, are given in Table XXIX.

TABLE XXIX.

RELATIVE CONDUCTIVITY OF PROTECTIVE COVERINGS.

Material Under Test	Temp. on Face of Protective Material °Fahr.	Temperature of Plate at Back of Protective Material (Degrees Fahr.)		
		Before Heating	After Heating 2 Hrs.	Heat Transmission
Terra-cotta: Dense, hollow, 2 ins. thick	1700	75	223	148
Terra-cotta: Semi-porous, solid, 2 ins. thick	1700	73	244	171
Plaster of Paris and shavings, 2 ins. thick	1700	69	159	90
Plaster of Paris and asbestos, 2 ins. thick	1700	70	163	93
Plaster of Paris, wood fibers, and infusorial earth, 2 ins. thick	1700	72	167	95
Concrete of ground cinders, 1 5-16 ins. thick	1700	73	363	290
Cinder concrete, on metal-lath, 2 ins. thick	1700	66	248	182
Metal lath and patent plaster, about ½ in. thick over 1-in. air-space	1700	76	296	218

* Joseph K. Freitag, C. E., in *Architectural Engineering.*

417. TILE COVERINGS.—Porous tile is the most efficient material among the baked-clay products for thoroughly protecting cast-iron or steel columns supporting walls or floors. Its thickness should be at least 2 inches. The blocks are often made with lugs on the inside, which rest against the column, leaving an air-space when required. When the columns are square they are commonly encased in square coverings made of partition blocks set so as to break joint. When the corners are required to be rounded they may be made so in the fire-proofing in different ways.

In setting the covering, long, straight, vertical joints should be avoided; and if in any case it is not possible to continuously break joint, the blocks should be bound together with metal clips and by wrapping with wire or metal lath.

Figs. 266 and 267 are photographs of common types of round column covering. Figs. 268, 269 and 270 show methods of covering with tile, channel columns, Z-bar columns and square columns respectively. Figs. 271, 272, 273 and 274 show methods of covering round columns, and Fig. 275 illustrates one method of covering a column and pipes together.

Fig. 276 shows a round column with three sections of covering, breaking joints, and with separate pieces of covering with inside lugs and outside ribs or corrugations for plastering, and with metal clips.

Fig. 277 is an illustration of the "Ideal" interior fire-proof columns made by Henry Maurer & Son. They are round, of radial bricks, or of sections shown, of either solid or hollow members, applicable to any diameter, and designed to take the place, in certain cases, of iron or steel columns. An iron cap or plate, placed on top, distributes the weight, which may be very heavy. The surfaces are ready for plastering. Courses of band-iron are used occasionally between horizontal joints, as in the "Phœnix" wall construction, and the columns may be further reinforced by upright steel rods imbedded in concrete.

In all column covering it is necessary to secure it so thoroughly that it cannot be displaced by streams of water from the firemen's hose; and the efficiency of column protection of tile is greatly increased by wrapping it with metal lath before plastering. Two layers of tiling or concrete may be used, the inner layer being wrapped with the lath, which is imbedded in the mortar, and all

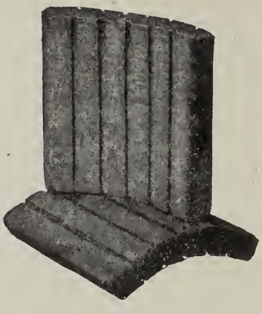


Fig. 266 Tile Covering for Round Column.

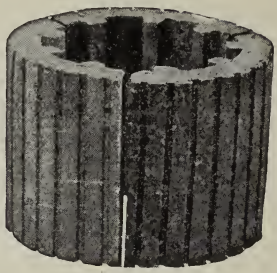


Fig. 267. Tile Covering for Round Column.

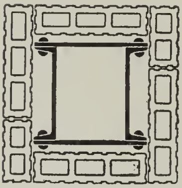


Fig. 268. Tile Covering for Box-column.

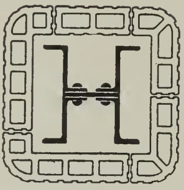


Fig. 269. Tile Covering for Z-bar Column.

Fig. 270. Tile Covering for Square Cast-iron Column.

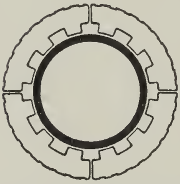


Fig. 271. Tile Covering for Round Cast-iron Column.

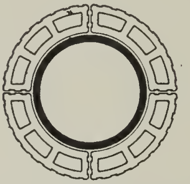


Fig. 272. Tile Covering for Round Cast-iron Column.

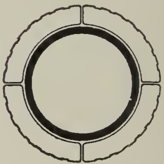


Fig. 273. Tile Covering for Round Cast-iron Column.

Fig. 274. Tile Covering Furred Out from Round Column.

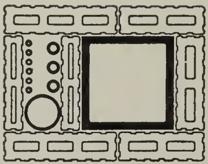


Fig. 275. Tile-covered Column with Pipe Space.

Above drawings reproduced through courtesy of National Fire-proofing Company.

spaces between the tiles and the metal column being solidly filled with cement mortar.

418. CONCRETE COVERINGS.—Iron or steel columns may be fire-proofed by using metal furring and metal lath, and by either filling inside of and around the lath with concrete or plastering on the lath and leaving an air-space. The furring may be framed out to any desired form or distance, and there may be one or two layers or coverings of the lath and plaster.

When concrete is used it may be placed to completely surround

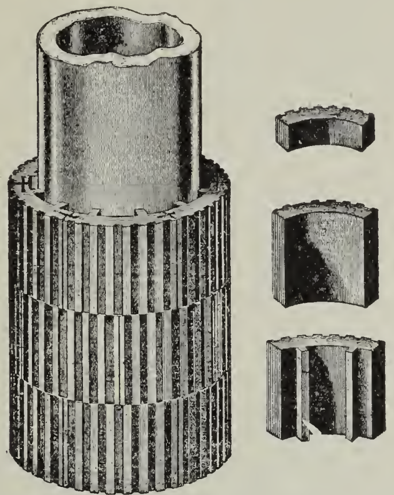


Fig. 276. Tile Coverings for Round Cast-iron Columns.

and protect the column, being poured inside of a temporary plank form built around it, placed usually at least 2 inches away, and in this case taking the place of the metal lath mentioned above. When lath is used it may serve both as a form to confine the concrete and as a guard to prevent it from being knocked off or washed away by water from the hose during a fire.

Concrete protection is better than that of lath and plaster, as it serves to strengthen the column and prevent corrosion. When a coating of liquid cement is first applied to the column, and when cinder concrete is used, a very efficient construction is obtained. When the concrete is put inside of wooden forms, metal lath wrapping is not necessary, but is always an additional safeguard.

Fig. 278 shows typical concrete covering for cast-iron columns,

round section, steel plate-and-angle columns and steel plate-and-channel columns.

Figs. 279 and 280 show concrete column coverings with steel rods imbedded and connected by means of ties of hoop-iron or wire according to the Hennebique system.

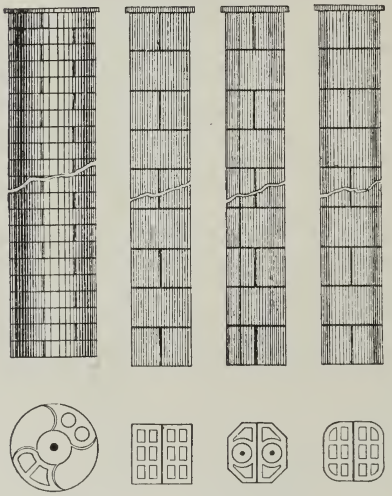


Fig. 277. Tile Columns.

Figs. 281 and 282 show Z-bar columns protected with concrete covering after the manner suggested by the Hinchman-Renton Fire-proofing Co.; Fig. 282 showing also a method of carrying pipes and wires up beside the column, and at the same time concealing them. Barb-wire is spirally wound around the column, and a wooden form is built, leaving the required space which is filled in solid with cinder concrete, covering also the wire. When the concrete has set and the form has been removed, plain wire lath is wrapped around the concrete

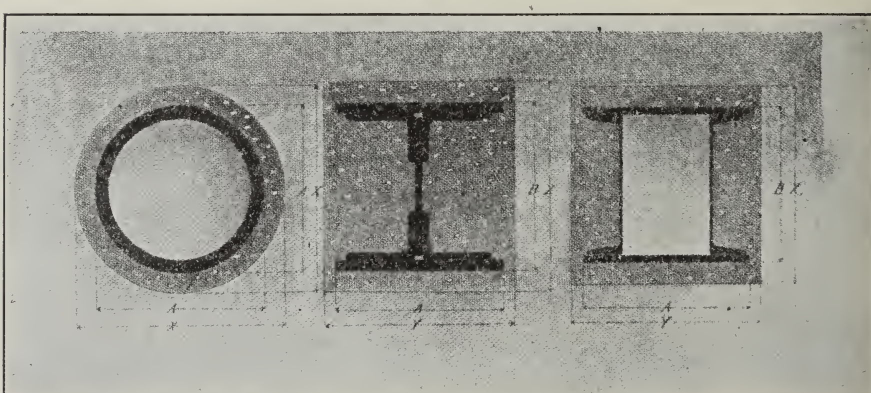


Fig. 278. Concrete Coverings for Different Column Sections.

and nailed to it, thus securely holding it in place. The column is then completed with any desired plaster finish.

Figs. 283, 284, 285 and 286 show steel box-columns and round

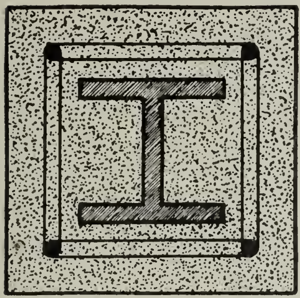


Fig. 279. Concrete Covering for Columns. Hennebique System.

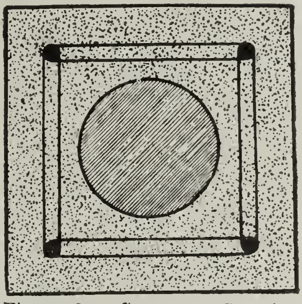


Fig. 280. Concrete Covering for Column. Hennebique System.

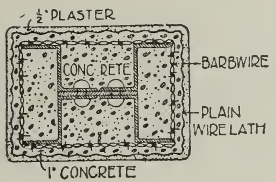


Fig. 281. Concrete Covering for Column. Hinchman-Renton System.

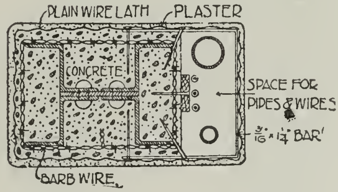


Fig. 282. Concrete Covering for Column. Hinchman-Renton System.

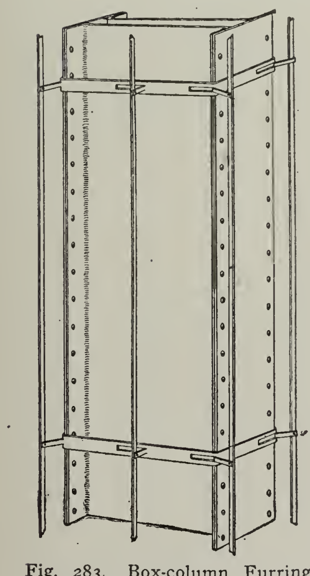


Fig. 283. Box-column Furring. Allunited Furring Strips.

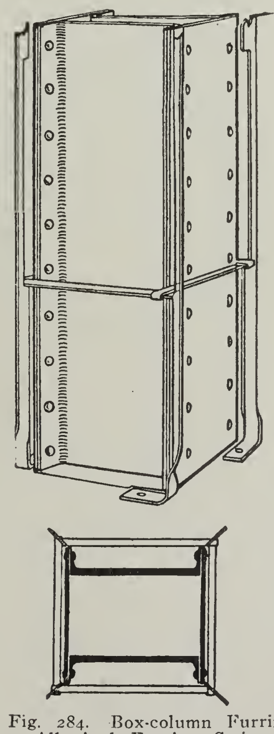


Fig. 284. Box-column Furring. Allunited Furring Strips.

cast-iron columns furred out for round and square concrete protective finish, with the Reliance Steel Furring made by the General Fire-proofing Company.

Figs. 287 and 288 show two column sections fire-proofed with concrete and plaster on wire lath as suggested by the Clinton Wire Cloth Company.

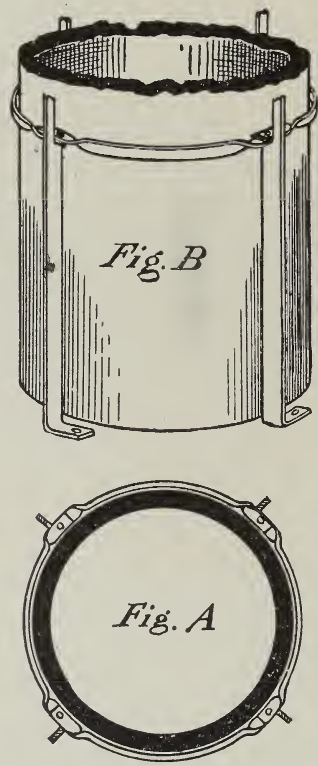


Fig. 285. Round Cast-iron Column. Allunited Round Furring.

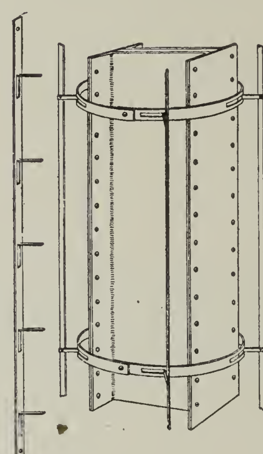


Fig. 286. Box-column. All-united Round Furring.

419. LATH-AND-PLASTER COVERINGS.—As has been previously stated, there are buildings in which the columns are protected by plaster on metal lath, in one or more layers, with air-spaces between. Two coverings are much better than one, which latter cannot be considered a fire-proof construction. Neither is as good as concrete. Aside from the question of protection from the heat of a severe fire, there is always danger that the powerful streams of water from the hose will knock off the plaster.

Figs. 289, 290, 291 and 292 show some column sections with the

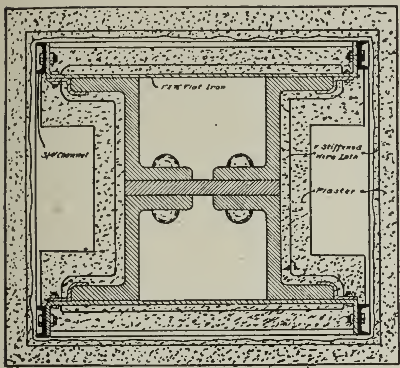


Fig. 287. Wire Lath and Concrete Covering for Column.

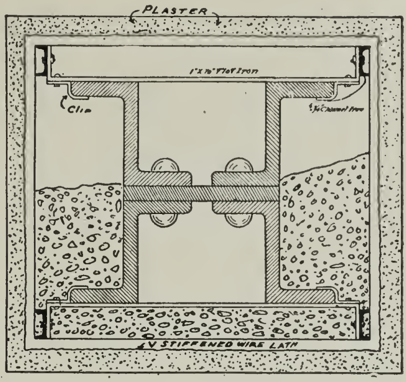
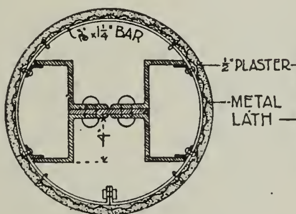
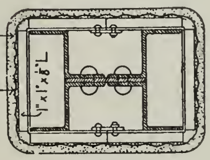


Fig. 288. Wire Lath and Concrete Covering for Column.



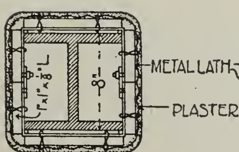
'A'

Fig. 289. Metal Lath and Plaster Z-bar Column Covering.



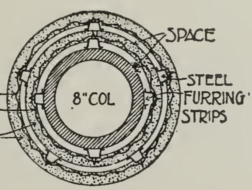
'B'

Fig. 290. Metal Lath and Plaster Z-bar Column Covering.



'C'

Fig. 291. Metal Lath and Plaster T-section Column Covering.



'D'

Fig. 292. Metal Lath and Plaster Round Section Column Covering.

Hinchman-Renton fire-proofing system of metal lath and plaster coverings.

The Roebling Construction Company has a good system of protecting columns, which involves furring them with vertical rods held in place by clamps, and then, by band-iron laced to the rods, bending stiffened wire lath around and lacing it to the furring. The space is filled with concrete and plastered, or wire lath and plaster alone is used; but of course without the same security.

Figs. 293 and 294 show two more methods, Fig. 294 being adapted to the use of expanded-metal lath.

Figs. 295, 296 and 297 show various lath-and-plaster protective

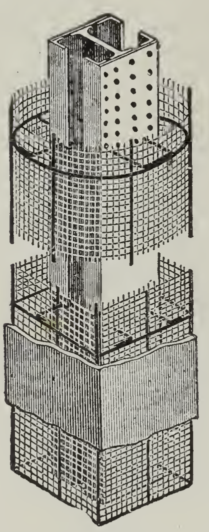


Fig. 293. Column Covering with Furring, Metal Lath and Plaster.

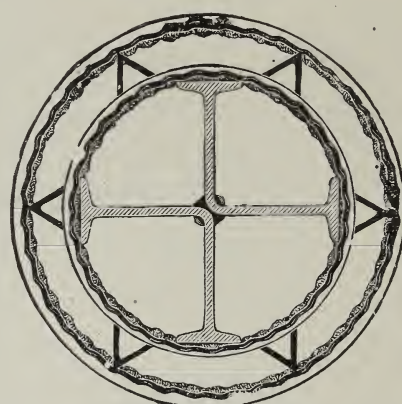


Fig. 294. Column Covering with Furring, Expanded-metal and Plaster.

methods for columns, suggested by the White Fire-proof Construction Company.

Fig. 298 shows the special lath for column protection made by the Rapp Fire-proofing Company. At the corrugations of the metal lath the plaster finds a solid bearing against the column.

Figs. 299 and 300 show false column constructions with metal lath and plaster coverings, suggested by the Clinton Wire Cloth Company.

False columns and pilasters are sometimes necessary, and when

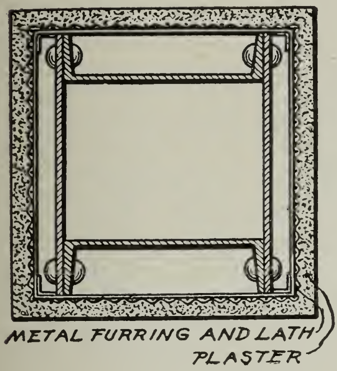


Fig. 295. Metal Lath and Plaster Box-column Covering.

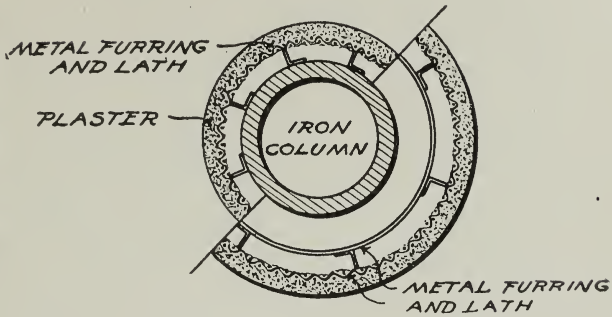


Fig. 296. Metal Lath and Plaster Round Column Covering.

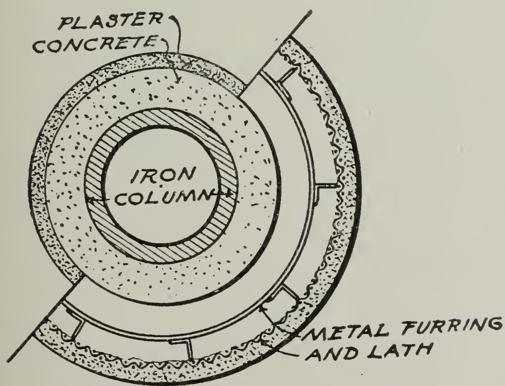


Fig. 297. Metal Lath and Plaster Round Column Covering.

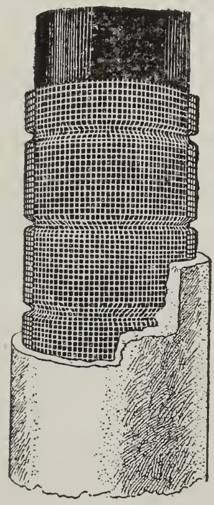


Fig. 298. Corrugated Metal Lath for Column Covering.

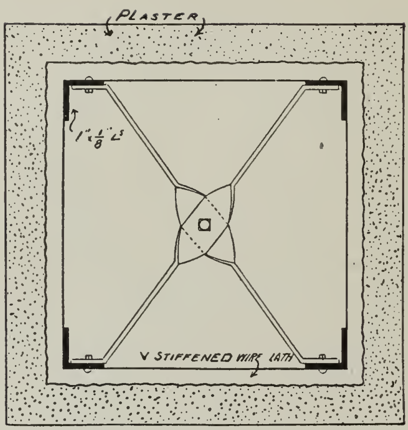


Fig. 299. False Square Column with Metal Lath and Plaster.

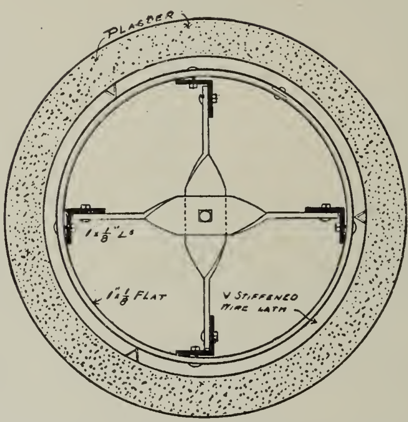


Fig. 300. False Round Column with Metal Lath and Plaster.

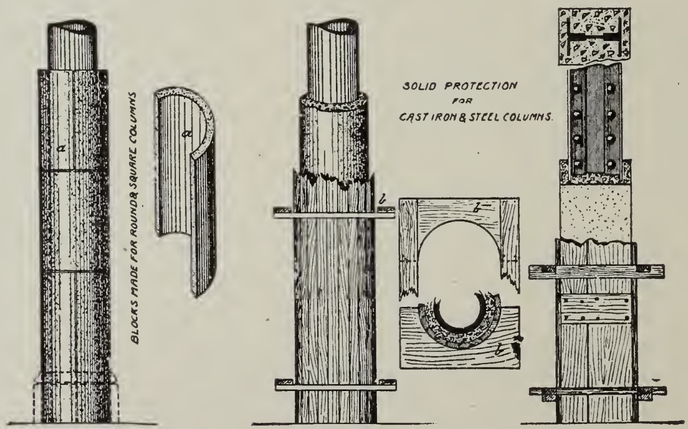


Fig. 301. Molded Block and Solid Concrete Column Covering.

built should be light and strong. The braces and the vertical furring should be bolted together, and not tied with wire.

420. PLASTER-BLOCK, CONCRETE-BLOCK AND COMPOSITION-BLOCK COVERINGS.—As a general rule column coverings of this kind are not desirable, because, while many of them have good non-conductive properties, it is often difficult to

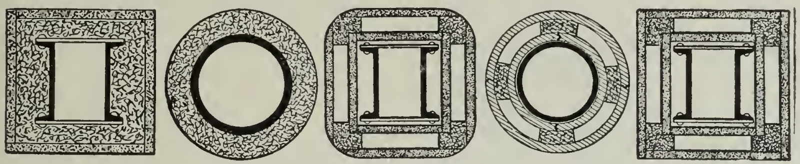
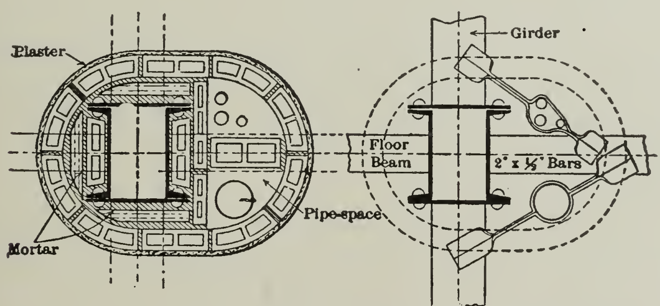


Fig. 302. Gypsite Tile Column Coverings.

fasten them securely in place. Those of plaster, especially, are apt to be washed away by water from fire hose.

Fig. 301 shows the molded concrete-block system of the Standard Concrete Steel Company for column fire-proofing. The blocks "a" are molded in the factory and there cured and made ready to erect immediately upon arrival at the building. They are made of the same concrete as the arches used in the floor systems.



Figs. 303 and 304. Method of Running Pipes Near Columns.

This same company has also a solid concrete protection for columns placed by means of a permanent form of wire cloth held in exact shape by an ingenious temporary form until the concrete has set. This also is shown in Fig. 301, at "b."

Fig. 302 shows cross-sections of columns covered with the "Gypsite" Tile of the Detroit Fire-proofing Company, the first two columns being covered solid, and the others having double layers of tiles and double air-spaces.

There are many other companies making different compositions for this purpose.

421. PIPES AND COLUMN FIRE-PROOFING.—It is generally convenient to run some of the pipes and wires near the columns as the latter are fixed permanently in place, and as many partitions are temporary and movable. When possible, these pipes and wires should be run in chases in permanent walls; but when they must be run up near some of the interior column-supports they should be placed entirely outside of the column fire-proof covering, and in an adjoining separately fire-proofed space. Recent conflagrations have shown how bad the old construction was, in which the pipes were placed next to the column-metal and inside its fire-proofing. In many cases their twisting and buckling threw off the coverings, exposing the columns directly to the flames and heat.

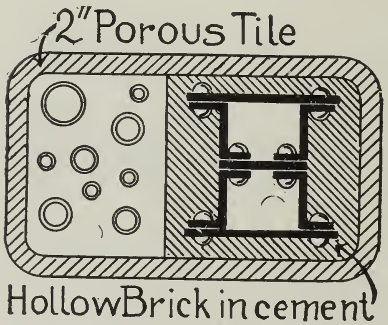


Fig. 305. Column and Pipe Covering in Monadnock Building, Chicago.

Figs. 303 and 304 show two of several recent methods employed for carrying pipes to higher stories, near columns, but arranged so as not to endanger them or their coverings in case of any tendency to bend or buckle.

See also Figs. 275 and 282.

Fig. 305 shows the method of running and concealing the pipes in connection with the fire-proofing of the columns, which was used some years ago in the first eight stories of the newer portion of the Monadnock Building in Chicago.

2. FIRE-PROOF FLOOR CONSTRUCTION.

422. GENERAL CONSIDERATIONS.—The improvements in fire-proof floor construction have been many and they have been made in rapid succession. Previous to 1880 so-called fire-proof floors were constructed of brick arches turned between the lower flanges of wrought-iron I-beams. These arches, with the concrete used for levelling, were very heavy, and as the bottoms of the beams were unprotected and the ceiling formed by the arches very unde-

sirable, brick arches soon gave place to arches of hollow dense tile. The increased demand for fire-proof construction, taken in conjunction with the reduction in the prices of steel and fire-proofing which occurred about the year 1889, led to many improvements in the designs for hollow tile floor arches, and also to the introduction of various systems of construction based upon the use of concrete and plaster compositions, combined with steel wires, bars and cables, used in different shapes and in different ways; the chief aim of the inventors or designers being to secure the lightest and most economical floor consistent with ample strength and thorough fire-protection.

In the following pages the author has endeavored to give an impartial description of most of the characteristic and leading types at present approved by leading architects and engineers.

The list is of course not all-inclusive, and there are systems and details in use, which have most excellent recommendations, but which have been omitted only because of the limited space in a general work of this kind.

423. STANDARD TESTS FOR FIRE-PROOF FLOOR CONSTRUCTION.—A greater amount of study has been given to fire-proof floor construction than to any other parts of fire-proof buildings; and because of the great importance of the subject, numerous tests have been made, principally under the auspices of various municipal authorities. New York City has led in this in the United States; and in Europe the British Fire Prevention Committee, of London, has added to our knowledge of the action of certain fire-proof floor constructions by the publication of a number of tests, the data for which, and also for tests made in the United States, appear in recent numbers of the "Proceedings of the American Society for Testing Materials."*

This latter society has recommended a standard test for fire-proof floor construction, and as its requirements are the same in all essentials as those of some of the building codes of large cities, it is given here as bearing directly on this part of the subject of the fire-proofing of buildings:

"The test structure may be located at any place convenient to the applicant, where all the necessary facilities for properly conducting the test are provided.

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*"Proceedings of the Am. Soc. for T. M.," Vol. VI., p. 128.

"The test structure may be constructed of walls of any material not less than 12 inches thick, properly buttressed on all sides.

"The floor construction to be tested shall form the roof of the test structure.

"At a height of not less than 2 feet 6 inches, nor more than 3 feet above the ground level, a metal grate, properly supported, shall be provided, covering the whole inside area of the building.

"In the walls below this grate level, draught openings shall be provided, as many as possible, furnishing openings with an aggregate area of not less than 1 square foot for every 10 square feet of grate surface. Means for temporarily closing these openings should be provided.

"In the wall, immediately above the grate level, a firing door, 3 feet 6 inches by 5 feet high, must be provided in the side of the building at right-angles to the floor beams. A second door must be added when the span of the floor slab under test exceeds 10 feet.

"Flues should be supplied at each of the corners, and oftener in case of a test-structure exceeding 250 square feet of grate surface, with sufficient opening to insure a proper draught, securely supported and disposed at the sides of the structure in such manner as not to rest on the floor under test. In no case should a flue area be less than 180 square inches.

"The horizontal dimensions of the test structure will depend upon the number and the span of the systems under consideration. The clear span of the floor beams is to be 14 feet. The distance between floor beams, or span of slab, may be varied according to the design of the system to be tested, and should be as near as possible to usual practice. The underside of the construction under test must not be less than 9 feet 6 inches nor more than 10 feet above the grate level.

"The construction to be tested should be designed for a working load of one hundred and fifty pounds per square foot, and no more. This load to be uniformly distributed without arching effect, and to be carried on the floor during the fire test.

"The floor may be tested as soon after construction as desired, but within forty days. Artificial drying will be allowed if desired.

"The floor is to be subjected to the continuous heat of a wood fire, averaging not less than 1700° Fahr. for four hours.

"The heat obtained shall be measured by means of standard pyrometers, under the direction of an experienced person. The type of

pyrometer is immaterial so long as its accuracy is secured by proper standardization. The heat should be measured at not less than two points when the main floor span is not more than 10 feet, and one additional point when it exceeds 10 feet. Temperature readings at each point are to be taken every three minutes. The heat determination shall be made at points directly beneath the floor so as to secure a fair average.

"At the end of the heat test a stream of water shall be directed against the under side of the floor, discharged through a one-and-one-eighth-inch nozzle, under sixty pounds nozzle pressure, for ten minutes.

"After the floor has sufficiently cooled, the load on the same shall be increased to six hundred pounds per square foot, uniformly distributed.

"The test shall not be regarded as successful unless the following conditions are met: No fire nor smoke shall pass through the floor during the fire test; the floor must safely sustain the loads prescribed; the permanent deflection must not exceed one-eighth inch for each foot of span in either slab or beam."

424. DIVISIONS OF THE SUBJECT.—The subject of fire-proof floor construction may be conveniently discussed under the following divisions and subdivisions.

a. Brick Fire-proof Floor Construction.

b. Terra-cotta or Tile Fire-proof Floor Construction.
   1. Segmental Tile Arches.
   2. Flat Arches, Side-construction.
   3. Flat Arches, End-construction.
   4. Flat Arches, Combination Side and End-construction.
   5. Block Tile or Lintel Construction.
   6. Flat Tile Construction, Reinforced.
   7. Guastavino Tile Arch Construction.

c. Concrete Fire-proof Floor Construction.
   1. Segmental Concrete Arch Construction.
   2. Flat Concrete Construction, Reinforced.
   3. Sectional Concrete Construction.

These various systems will be considered in the above order, but before discussing them it is convenient just here to mention briefly the steel framing for fire-proof floors, as it is so intimately connected with the flooring masonwork.

425. STEEL FRAMING FOR FIRE-PROOF FLOORS.—Two figures are given, Fig. 306, illustrating the typical steel beam and girder floor framing for long-span construction, and Fig. 307, illustrating the typical arrangement for short-span construction.

It is a general principle, holding true with any kind of filling between the girders and beams, that for moderate spans a smaller amount of steel is required than for very wide spans.

The system of fire-proof floor construction is decided upon before the steel framing plans are made, a long-span system necessitating

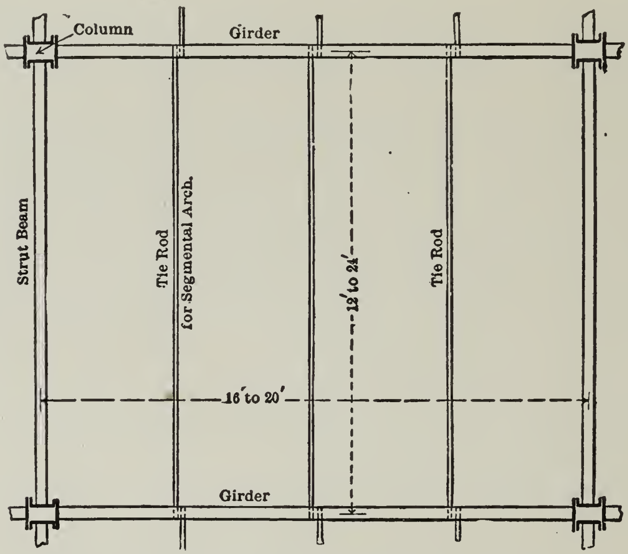

Fig. 306. Typical Framing for Long-span Construction.

an arrangement of the girders similar to that shown in Fig. 306, while an ordinary short or moderate-span system, such as the usual flat tile arches, necessitates floor beams framed into the girders and spaced at varying distances apart, ranging from 5½ to 9 feet, and similar to the construction shown in Fig. 307. The "strut-beams" shown in Fig. 306 are put in the long-span construction between the columns, to which they are riveted, and add to the rigidity of the building both during and after its erection.

With the omission of the floor beams, the architect is restricted in his choice of floor construction to comparatively few systems,

while a construction including the use of floor beams permits the use of almost any system of fire-proof floors.*

2. *a.* BRICK FIRE-PROOF FLOOR CONSTRUCTION.

426. GENERAL DESCRIPTION.—Fig. 308 illustrates the early attempts to construct fire-proof floors by turning brick arches of one or more row-locks from the lower flanges of wrought-iron I-beams. This brick construction with steel beams is occasionally used to-day, in such buildings as warehouses and in some of those in which the arched ceiling spaces are not considered objectionable.

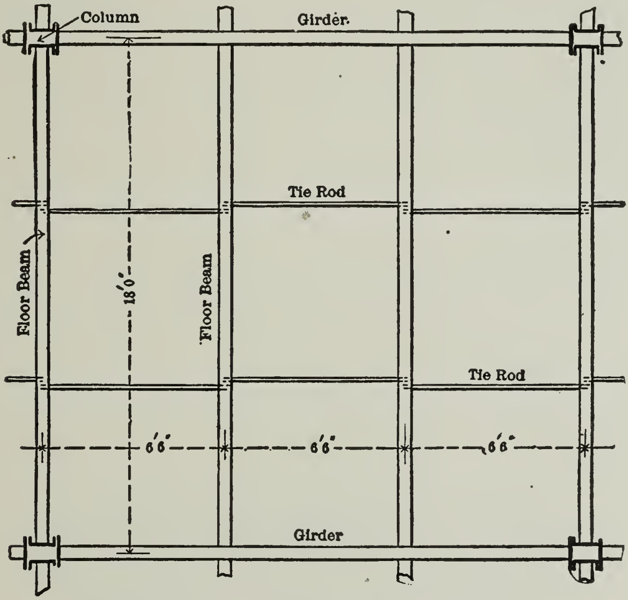

Fig. 307. Typical Framing for Short-span Arches.

Fig. 309 shows the method of protecting the lower flanges of the beams by terra-cotta skew-backs.†

The recommendations for brick floor-arches are their great strength in proportion to the span, their resistance to suddenly applied loads or severe pounding, and their elasticity and great deflection before failure.

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* For a discussion of the subjects of "Computations for the Steel Framing," "Tables for Floor Beams," "Tie-rods," "Load Tests," etc., see the "Architect's and Builder's Pocket-Book," by Frank E. Kidder, Chapter XXIII.

† The construction shown in Fig. 309 is the one used in the principal floors of the Government Printing Office at Washington, and is described in the *Engineering Record* for Dec. 6, 1902.

The objections to them are their great cost when the increased expense of the metal framework necessitated by their heavy weight is included, and, for most buildings, their unsightly appearance as ceilings.

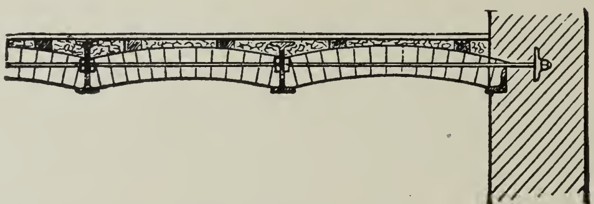

Fig. 308. Early Form of Wrought-iron Beam and Brick Arch.

The following data will be found useful in connection with this type of construction:

Weights.—For a floor similar to that shown in Fig. 308, from 70 to 75 pounds per square foot, varying with the weight of levelling concrete.

Thicknesses.—For spans up to 7 feet 4 inches. For spans over 7 feet, not less than 8 inches. Some engineers advise a thickness of 8 inches for spans over 5 feet. A span between 4 and 6 feet makes the most desirable span.

Haunches.—Filled level with top of arch with "wet" cement and gravel concrete.

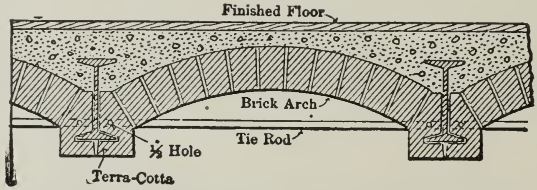

Fig. 309. Brick Floor Arch with Beam Flange Covering.

Rise.—One-eighth of the span or 1½ inches to the foot.

*Tie-rods.**—Always provided, as segmental arches exert considerable thrust, and the outer bays, especially, tend to spread. Spacing of rods, eight times the depth of supporting beam, but never more than 8 feet. Located in line of thrust of arch, usually below middle depth of beam, and sometimes near bottom flange. Run continu-

* For a discussion of the correct methods of computing the thrusts of floor arches, and of proportioning and spacing tie-rods, see the "Architect's and Builder's Pocket-Book," by Frank E. Kidder, Chapter XXIII.

ously, from beam to beam, and when a steel angle, as in Fig. 308, is used instead of a wall beam or channel, anchored into wall with plate-washer, as shown.

Tie-rods are always desirable, no matter what system of tile arches is used.

Strength.—When thoroughly grouted and levelled with Portland cement concrete, a 6-feet span, 4-inch brick arch will carry safely from 300 to 400 pounds to the square foot.

Bricks.—Hard, thoroughly burned common bricks, or approved-shape hollow bricks.

Manner of Laying Bricks.—Laid on centers, and laid to a line. Bricks of adjoining lines in same row-lock break joint with each other; and when there are several row-locks the joints of the adjoining row-locks break joint with each other. Bricks laid in place without mortar, the joints being afterward carefully filled full with cement grout.

Skew-backs.—For unprotected beam-flange construction, common bricks cut to proper shape, as in Fig. 308; for first-class fire-proof construction, lower flanges of beams covered with specially made terra-cotta skew-backs, as in Fig. 309.

Brick Floor Construction. Rapp System.—This system combines the strength of the ordinary row-lock brick arch with that of steel T-ribs, and an arched form of concrete above both.

It is described and illustrated under "Segmental Concrete Floor Arches," in Article 443.

2. *b.* TERRA-COTTA OR TILE FLOOR ARCH CONSTRUCTION.

427. GENERAL CONSIDERATIONS.—The different kinds of terra-cotta or tile used in fire-proofing construction have already been mentioned under "Fire-proofing Materials," Article 407.

The following are some of the advantages of terra-cotta floor arch construction:

1. Rapidity of installation.

2. Greater stiffening effect in the structure against lateral forces, such as wind, than results from other types of floor construction.

3. Supervision necessary during installation less than for systems in which the materials are mixed as they are put in place.

4. Greater opportunity and possibility of judging accurately the quality of material used before and after setting in place.

5. Comparative cleanliness of the work of putting in place, and

consequent non-interference with the work of other mechanics on floors below.

The following are some of the disadvantages of terra-cotta floor arch construction:

1. Frequent excess of weight over that of concrete systems, on account of necessary concrete filling over arches, causing increase of total cost.

2. Difficulty of adapting systems to fill spaces of irregular shape.

3. Difficulty and consequent increased cost of adapting systems to varying widths of spans between beams.

4. Liability of breakage and chipping in floor blocks.

5. Greater weakening on account of holes for pipes than that which takes place in monolithic floors.

428. MANNER OF SETTING TILE ARCHES.—Hollow tile arches of whatever type should be set in a Portland cement mortar on plank centering, slightly cambered.

In warm weather all tile should be well wet, and in freezing weather kept dry.

A good mortar is made of one part Portland cement added to three parts rich cold lime, and one still better is made by mixing the cement and sand, and then adding enough cold lime putty to make it work smoothly. The use of hot lime mortar is never advised, nor mortar of cement and sand alone for porous hollow tile.

The best centering for flat arches is that in which the planks run at right-angles to the beams and rest on 2 by 6-inch sound lumber center pieces, placed midway between the beams and extending parallel with them. These center pieces are supported by T-bolts from like center pieces above, crossing the beams. The planks on which the tiles are laid should be 2-inch planks, dressed on one side to a uniform thickness and laid close together. If the soffit tiles are separate pieces they should first be laid directly under the beams on the planking; if projecting skew-backs are used, they must first be set, after which the centering is tightened by screwing down the nuts on the T-bolts until the soffit tiles, or skew-backs, are hard against the beams and the planking has a crown not exceeding ¼ of an inch in spans of 6 feet. This system gives what is very essential, a firm and steady center on which to construct the flat tile work. The tiles should be shoved in place, with close joints; and keys should fit close, but should never be rammed into place.

The centers should remain from twelve to thirty-six hours, according to the condition of the weather, the depth of tiling and the mortar used. In cold or wet weather it is better to allow 48 hours or even a still longer period. When centers are "struck," the ceiling should be straight, even, free from open joints, crevices and cracks and ready to receive the plastering.

Wherever openings are required through the floor they may be made by punching a hole through the blocks; or, if the side-method arch is used, a single block may be omitted. Small holes may afterward be plugged up with mortar and broken pieces of tile.

The variations in width of spans between beams is provided for by supplying tiles of different sizes, for both interiors and keys, thereby securing a variety of combinations. A great variety of skew-backs also are provided for fitting different sizes of beams.

429. PROTECTION FROM STAINS, WEATHER, ETC.—The laying of flat construction in winter weather without roof protection should not be practiced in climates where frequent severe rain and snowstorms are followed by hard freezing and thawing, as the mortar joints are liable to be weakened or ruptured, resulting in more or less deflection of the arches. Porous terra-cotta is liable to be utterly ruined if frozen when water-soaked. When it is intended to plaster on the under side of the arches, the architect should see that the smoke and soot from the boiler used for the hoisting engine are not allowed to strike the arches, as they are sure to stain the plaster, and as neither can be removed. For the same reason the architect should see that clean water only is used for mixing the mortar, and that it is not allowed to flow over the arches.

Where flat tile arches have been used, many architects have had trouble from stains and efflorescence appearing on the plastered ceilings after the latter has become dry. Such stains are due to the effects of iron in the clay, or to the cinders in the concrete over the arches when the floors become very wet, or to other causes. Such stains cannot always be concealed, even by oil paint; and the only way in which they can be avoided is by observing the above precautions and by not plastering until the arches are well dried out. A coating of some one of the many hydraulic paints now on the market, applied to the bottom of the arches before plastering, is

recommended as a safe precaution against stains. Some of these paints have proved very effective.

The architect should also see that the green arches are not overloaded with building material by the other contractors.

430. FLOOR AND CEILING FINISH.—*The under side* of flat tile arches is usually finished with two coats of plaster applied directly to the bottom of the tiles. If there are inequalities in the surfaces of the arches they should be filled with natural cement-and-sand mortar before plastering. False plaster beams may be formed on metal furring, bolted to the under side of the arches and covered with wire lathing, or the furring may be of wood, as its consumption in case of fire would in no way endanger the building. Metal furring, however, is better, as it does not shrink.

Wood furring strips to form nailings for wood moldings, etc., may be secured to the soffits of the arches by punching slot holes in the bottom of the blocks and inserting T-headed bolts.

The upper surface of the arches are generally covered with concrete of a sufficient depth to allow for bedding in it the wooden strips to which the floor boards are nailed.

The general custom in regard to the size of floor strips is to use strips made dovetail shape, about $2\frac{1}{2}$ inches wide at the top, $3\frac{1}{2}$ inches wide at the bottom, and from $1\frac{3}{4}$ to 2 inches thick, and laid at right-angles to the beams and 16 inches apart from centers. The concrete is first levelled to the tops of the highest beams and the strips then laid in place by the carpenter. The mason then fills between the strips to within $\frac{1}{4}$ of an inch of their tops with concrete pressed down hard against them. The flooring is then nailed to the wooden strips. In New York 3 by 4-inch strips have been used, the strips being notched down 1 inch over the beams. The strips, also, do not always run at right-angles to the beams, although the general opinion appears to be that they should do so wherever practicable.

The general custom among many Western architects is to allow $3\frac{1}{2}$ inches from the tops of the beams to the top of the finished floor. This gives a sufficient space between the beams and flooring for running gas pipes or water pipes, as shown in Fig. 310. Wherever buildings, and especially office-buildings, are piped for gas, it is absolutely necessary to leave sufficient space between the tops of

the steel beams and the bottom of the flooring for the running of branches to center outlets.

Wherever the nailing strips cross the floor beams or girders they should be fastened to them by means of iron clamps, made so that one end can be hooked over the flange of the steel beam and the other end driven into the side of the wood strip. When the strips run parallel with the beams it is good practice to nail pieces of hoop-iron across the under sides of the strips, about 4 feet apart, to hold them more firmly in place, as concrete alone does not

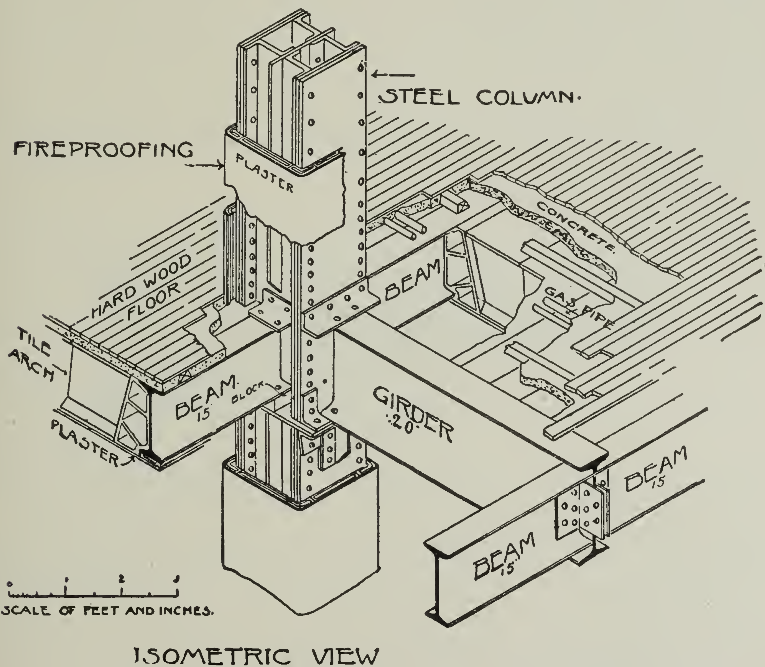

Fig. 310. Column Covering and Floor Construction, "Fair" Building, Chicago.

hold them with sufficient firmness. The hoop-iron strips should be 1½ by ⅛ of an inch in section and 10 inches long, and should be secured by two clout nails.

The concrete used for the filling on top of the arches should be a rich cinder concrete, mixed with Portland cement, brought level with the tops of the steel beams, and thoroughly tamped. When the tile arches are well wet, and covered with this concrete, their strength is greatly increased. A thin coat of Portland cement-and-sand grout put on with a brush should be applied to the tops of the steel beams,

after the nailing strips are in place; and the spaces between the latter should be filled with a 1 to 8 or 10 cinder concrete. The concrete must become thoroughly dry before the flooring is laid.

Occasionally, where the beams are of unusually long span, a 10-inch or 12-inch arch is set between 15 or 20-inch beams. In such cases hollow terra-cotta filling blocks may be used to fill in to the tops of the beams, as shown in Fig. 328. Their recommendation is their lightness compared with good concrete; while the objection to them is that they do not add any strength to the arch unless carefully set in cement mortar, and unless the tiles and the tops of the floor arches are thoroughly soaked just previous to laying the filling blocks.

If the floors are to be tiled, the concrete between the bottom of the tiles and the top of the arch should be made of Portland cement, sand and crushed stone.

In the case of cement-finished floors a space of from 2½ to 3

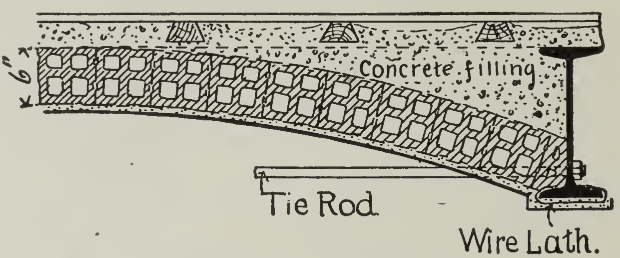

Fig. 311. Common Form of Segmental Floor Arch.

inches is not too much to allow for the cement and concrete above the steel beams. It is usually blocked out in sections of 6 feet square, or less, with joints made to extend through the concrete; and, when possible, the joints in one direction are made to come over the beams.

Fig. 310 shows the floor construction used in the "Fair" Building, Chicago, Jenney & Mundie, architects, and shows also the fire-proofing of the columns. The construction shown in this cut is typical of many other buildings also.

431. *b*. 1. SEGMENTAL TILE-FLOOR ARCHES.—Where a flat ceiling is not essential, and for warehouses, factories, lofts, sidewalks, breweries, etc., the segmental arch gives the strongest, best and cheapest (considering the saving in ironwork) fire-proof floor that can be built of tile. Segmental arches can be used for spans up

to 20 feet, thus dispensing entirely with the usual floor beams; but it is better to set the limit at about 16 feet. They also effect a considerable saving in the dead weight of the floor, thereby permitting the columns and girders to be made lighter.

The commonest form of segmental arch is that shown in Fig. 311. It is made of hollow blocks, usually 4, 5, 6 or 8 inches square and 12 inches long, the tiles being laid so as to break joint longitudinally of the arch, as shown in Figs. 315 and 316. Nearly all manufacturers of hollow tiling make one or more shapes for segmental arches, and also different styles of skew-backs to use with them. These arches are also made of hollow brick, "Haverstraw" size. No form of tile floor arch construction should be used in which the blocks are single-celled. In driveways, where heavily loaded trucks and teams pass over them, the double row-lock hollow brick arches are preferable.

Semi-porous segmental tiles usually have webs from ½ to ⅝ of an inch thick; and porous tiles, webs ¾ of an inch thick, the skew-back being ¾ of an inch and 1 inch thick, respectively, for the same materials. Special cases need greater thicknesses. Webs of New York tiles are generally thicker than those of Chicago tiles, which are often stronger than the former.

Hollow tiles for segmental arches are made of dense, semi-porous and porous tiling.

The National Fire-proofing Company states that "end-construction blocks may be used, but they are unsatisfactory, unless the arches are of uniform span and rise throughout. The rise of the side-construction arch can be varied by increasing the thickness of the upper or lower part of the mortar joint; but this cannot be done with the end-construction method." Figs. 312, 313, 314, 315 and 316* show several types of segmental tile floor arches in general use. Fig. 317 shows photographs of typical blocks. The large blocks with large openings are lighter and cheaper to lay than the smaller ones. The skew-backs showing rounded surfaces under the beams are cheaper to plaster on than skew-backs with sharp edges. When an arch is raised at the skew-backs the arch is flattened, the dead load of concrete at the haunches is reduced, and the strength of the arch decreased.

* Courtesy of National Fire-proofing Co., Henry Maurer & Son and Gladding, McBean & Co.

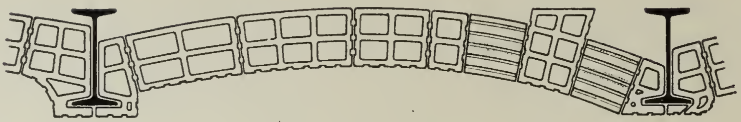

Fig. 312. Types of Skew-backs and Keys.

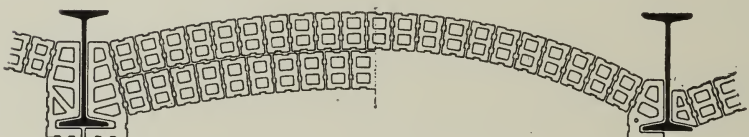

Fig. 313. Double and Single Row-lock Arches. Hollow Bricks.

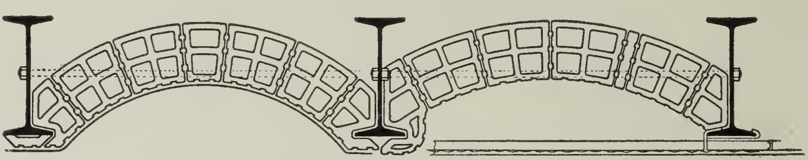

Fig. 314. 1. Plastered Arch. 2. Metal-lath Ceiling.

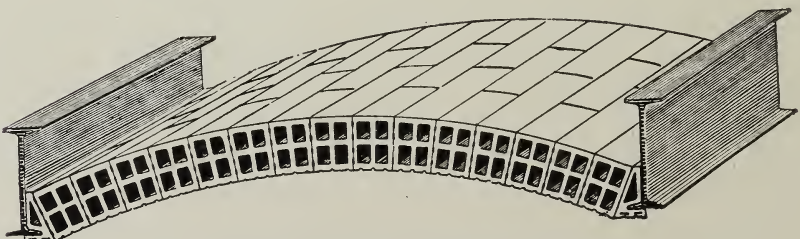

Fig. 315. Segmental Tile Floor Arch.

The raised block shown in Fig. 312 has been used in very wide spans, its object being to bring the concrete back of it into compression, and to relieve to some extent the pressure on the skew-backs.

Segmental arches should have a rise of not less than 1 inch per

Fig. 316. Segmental Tile Floor Arch.

foot of span, and 1½ inches wherever practicable. The rule is sometimes given, that the rise of the soffit of the arch above the spring line should be from 1-10 to ⅛ of the span. As the rise increases, the thrust decreases.

The considerable thrust of these arches should be taken up by ample tie-rods. The lower third of the beams is the location indicated for greatest efficiency. But when placed within the lower

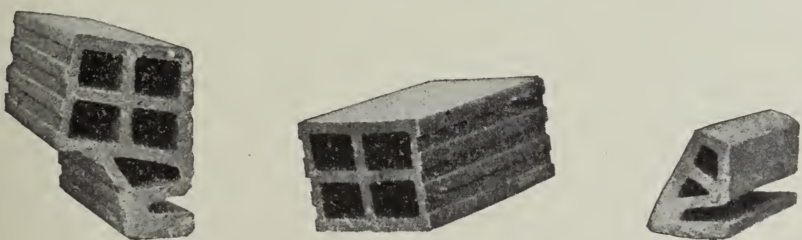

Fig. 317. Typical Tile Skews and Key.

third of the beam they show on the ceiling. In this case they are either painted and left unprotected, or hidden by a metal lath and plaster ceiling, or occasionally encased with a specially made tie-rod tile.

With this type of arch sometimes very heavy or solid skew-backs are used without the flange projection, as the thrust on the skew-backs is very great where an arch is of wide span. In this case the bottom flange of the beam is covered with heavy, stiffened wire

lath before the skew-backs are set. When plastered the ceiling has the appearance shown in Figs. 311 and 314, the latter showing, in the right half of the illustration, a very light, strong arch with deep beams, with flat ceiling formed by using metal lath and plaster suspended below.

Weight and Strength.—The segmental form of arch is undoubtedly the strongest that can be built, whether of brick, hollow tile or concrete. The following are the average weights for various ordinary segmental arches:

Solid brick segmental arch, 4-inch, 38 pounds per square foot.
Solid brick segmental arch, 8-inch, 80 pounds per square foot.
Hollow brick segmental arch, 4-inch, 31 pounds per square foot.
Hollow brick segmental arch, 8-inch, 65 pounds per square foot.
Hollow tile segmental arch, 6-inch, 26 pounds per square foot.
Hollow tile segmental arch, 8-inch, 32 pounds per square foot.

The weights of the flooring, concrete, plaster, sleepers, I-beams, etc., must be added to the above weights in order to obtain the total dead load.

In the celebrated Austrian tests* a common brick arch 5½ inches thick and 8 feet span, with a rise of 9.85 inches, carried an eccentric load of 885 pounds per square foot before failing. The failure was then caused by buckling and not by crushing. A porous tile arch of 15 feet 4 inches span, with a rise of 16 inches, built with 6-inch hollow blocks for a distance of 7 feet 8 inches across the middle part and with 8-inch blocks for the balance, was tested by loading one side with a pile of bricks measuring 4 feet 6 inches lengthwise of the arch and 7 feet 6 inches in the direction of the width. When the weight reached 42,000 pounds (1,235 pounds per square foot), the unloaded side commenced to buckle, and in 30 minutes collapsed.†

Complete tables of the strength of all types of floor arches are given in the various handbooks and manufacturers' catalogues, and the reader is referred to them and to Kidder's "Architect's and Builder's Pocket-Book," which contains condensed tables compiled for reference in those cases occurring oftenest in general practice.

Setting.—Segmental arches are set in the same way as flat tile arches, except that the wood centers are arched to the desired curve and suspended at the sides by hooks passing over the beams or girders. The bottoms of the hooks are made round, and have a

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* *Architecture and Building*, January 4, 1896.
† *Engineering Record*, April 14, 1894.

thread and wing-nut to bring the center into its proper place and to lower it after the arch has set.

Holes are left where the hooks pass through the arch, and after the centers are removed these holes are plugged with mortar and pieces of tile.

Good cement concrete should be used to fill the haunches, the top surface being levelled off to a height which is not less than 1 inch above the crown of the arch. Cinder concrete filling may be used for short spans, but as the strength of a floor arch at the haunches depends in great measure upon the strength of the concrete filling, gravel concrete should be used for wide spans.

When it is desired to lighten the construction, voids are occasionally formed in the concrete of the haunch-filling, by inserting cores of stiff pasteboard or of other composition.

432. *b.* 2. FLAT TILE FLOOR ARCHES. SIDE-CONSTRUCTION. *Classification and General Description.*—Originally, in the early development of tile systems of fire-proof arches, there were recognized three general schemes of flat tile construction. The first and oldest is known as the "side-construction," in which the tiles lie side by side between the beams, as shown in Figs. 318, 319, 320 and 322. In the second scheme, known as the "end-construction," the blocks run at right-angles to the beams, abutting end to end, as shown in Fig. 323. The third method, the "combination side-and-end-construction," is a cross between the first and second, the skew-backs, and sometimes the "keys," being made as in the side-construction, and the "interiors" abutting end to end between them, as shown in Figs. 333 and 334. This method was known by different names, such as the "Johnson Arch," the "Excelsior Arch," the "Combination Arch," etc.

At the present time the usual classification includes but two subdivisions, the "side-construction" and the "end-construction," as the latter is now usually put in place with side-construction skew-backs and with either end-construction or side-construction keys.

Early Forms and Later Improvements.—The hollow tile floor arches first used in this country were made of dense tile, formed essentially like those shown in Fig. 318, except that no provision was made for protecting the bottoms of the beams other than the plastering of the ceiling. It was soon found that the bottoms of the beams must be more thoroughly protected from heat, as they warped

and twisted so badly during a fire that the destruction of the building was threatened. The skew-backs were, therefore, made so as to drop from ¾ to 1 inch below the bottoms of the beams, and so

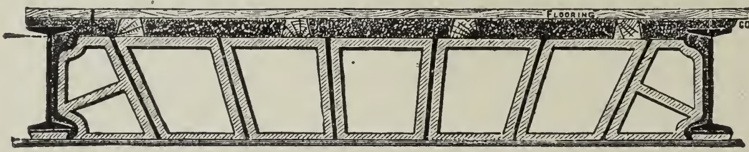


Fig. 318. Early Example of Side-Construction Floor Arch.

as to either extend under the beams or hold thin tiles dovetailed between them, as shown in the figure. Arches of this type were used for several years, but it was found that they were not strong enough to sustain heavy loads and sudden stresses, such as those caused by the moving of heavy safes, nor to withstand the rough

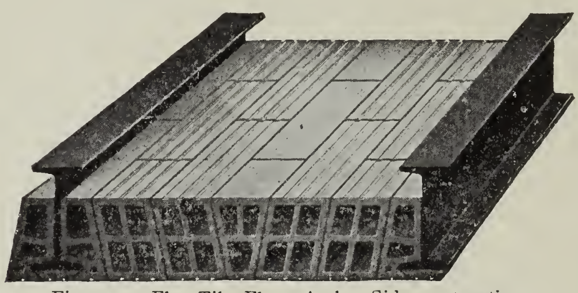


Fig. 319. Flat Tile Floor Arch. Side-construction.

treatment and heavy weights that floors are subjected to while buildings are in course of erection. The blocks were, therefore, strengthened by the introduction of horizontal and vertical webs, resulting in the shapes shown in Figs. 319 and 320, which represent types of arches with ribs parallel to beams. Flat arches are made up of

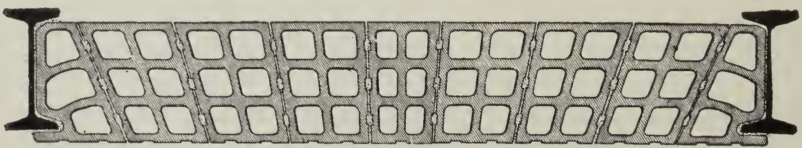


Fig. 320. Flat Tile Floor Arch. Ribbed Side-construction.

various-shaped blocks, as shown in the drawings and photographs. Figs. 321 and 322 show typical block shapes and different methods of assembling various members of an arch. Skew-backs may be either "plain," without protection for the under sides of the beams;

"lipped," having a projection molded on the blocks; or "soffit-skews," in which the protection is a loose slab held in place by the bevel on the blocks. The intermediate blocks are called "lengtheners," and the middle one the "key."

Arches similar to these are now generally made of semi-porous tiling. The end-construction is rapidly displacing this side-construction, on account of the former's greater strength for the same weight of material.

Joints.—Most of the side-construction arches have bevelled joints, which are parallel to the sides of the keys, as shown in Fig. 319, although arches have sometimes been specified and made with radial joints, as shown in Fig. 320.

Theoretically the radial joint should make a stronger arch; but the increased cost of making so many different shapes of blocks and the endless confusion and delay in setting prevent it from being much used.

The blocks in the side-construction arches break joint endwise, thus completely bonding the arches, as shown in Fig. 319; and the failure of any single block does not impair the strength of an arch beyond that block. In that respect the side-construction is superior to the end-construction.

Depth.—A general rule is that flat floor arches should be of the same depth as the floor beams supporting them. For the same depth of beams a lighter and cheaper floor, as well as a stronger one, is obtained by using deep rather than shallow blocks, a 12-inch arch, for example, weighing less per square foot, and also costing less, than a 10-inch arch covered with 2 inches of concrete.

In practice the custom is to proportion the depth of an arch to the span between the beams and to the load. A safe general rule is to make the depth of the blocks 1¼ inches for each foot of span, adding the thickness of the protection below the beams. Some building laws require a greater depth than this rule gives.

Webs.—The webs are arranged in various combinations, as shown in the illustrations, and should be not less than ⅝ of an inch thick. There should always be a strong web-piece in the skew-back near the bottom and at the lower flange of the beam and in the line of greatest pressure. To reduce the weight this web is sometimes omitted; but this should never be allowed, as floor arches have collapsed from this omission alone.

Safe Loads and Weights.—For safe loads for different spans, and for weights of arches of the side-construction, the reader is referred to the complete tables of the manufacturers' handbooks; and to condensed tables of the same in Kidder's "Architect's and Builder's Pocket-Book."

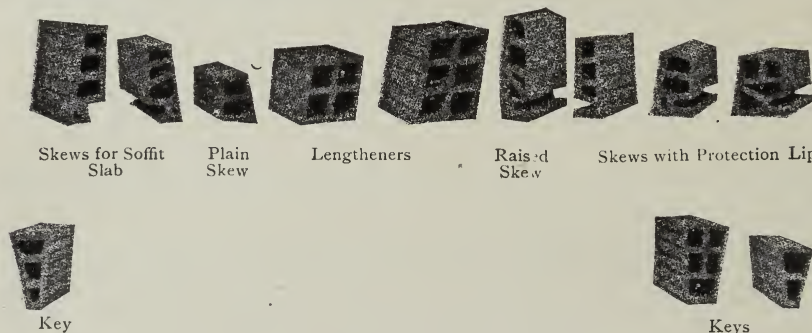


Fig. 321. Typical Tile Floor Blocks.

433. *b.* 3. FLAT TILE FLOOR ARCHES. END-CONSTRUCTION. *General Description.*—In this method the blocks are generally made approximately rectangular in shape, with vertical and horizontal partitions, and with bevelled end-joints. Figs. 323 to 332 show typical sections and views of blocks and different forms of arches of the end-construction. The pressure on the blocks is endwise of the tiles; as the sides and voids run at right-angles to the I-beams. End-construction is taking the place of side-construction, as it is stronger for the same amount of materials.

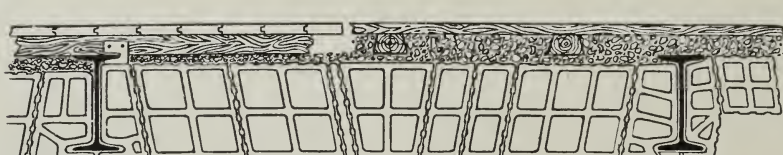


Fig. 322. Tile Floor Arch—Typical Side-construction Section.

Early Forms and Later Developments.—One common type of end-construction arch is that shown in Fig. 323, which was first brought into general use by Mr. Thomas A. Lee, and which has been often designated as the "Lee End-method Arch." It has the advantage of simplicity and economy in manufacture, as all the blocks for a given depth of arch can be made with one die. Manufacturers making this type of arch use porous and semi-porous terra-cotta in its con-

struction. Fig. 325 shows an isometric view of one of the skew-backs.

Figs. 326, 327 and 328 represent variations of a type of floor arch, invented and patented by Mr. E. V. Johnson, formerly of the Pioneer Company, of Chicago. Fig. 326 shows the original shape.

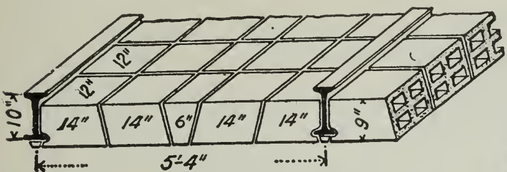


Fig. 323. End-construction Tile Floor Arch.

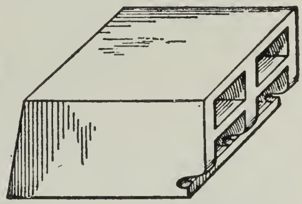


Fig. 325. End-construction, Abutment Piece or Skew.

In order to obtain a stronger, although slightly heavier, arch the shapes were changed to those shown in Figs. 327 and 328, by Henry Maurer & Son, of New York, who, with the Pioneer Company and the Haydonville Company of Ohio, bought the right to make and sell this arch. The Pioneer Company originally used a side-construction skew-back, as in Figs. 327 and 328, but changed to the end-construction form, as in Fig. 326. Messrs. Maurer & Son use the side-construction skew-back.

Semi-porous material is used for these forms of floor arches. They are considered good types and have been largely used. The

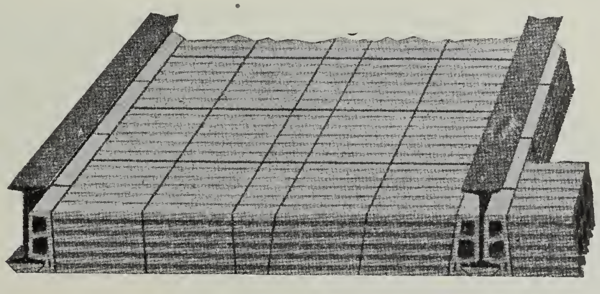


Fig. 324. End-construction with Side Skews.

shape of the blocks leaves ample space for the tie-rods, thus avoiding cutting. The arches may be used in spans up to 10 feet, and the depth has been made as great as 20 inches, with a weight of 56 pounds per square foot.

The arch shown in Fig. 328 is called the "Excelsior" arch, and its

limits of span, weights per square foot and the safe loads allowed on it are given in Kidder's "Architect's and Builder's Pocket-Book."

Objections to End-construction.—One objection against this is that it is difficult to properly bed the edges of the blocks, and that

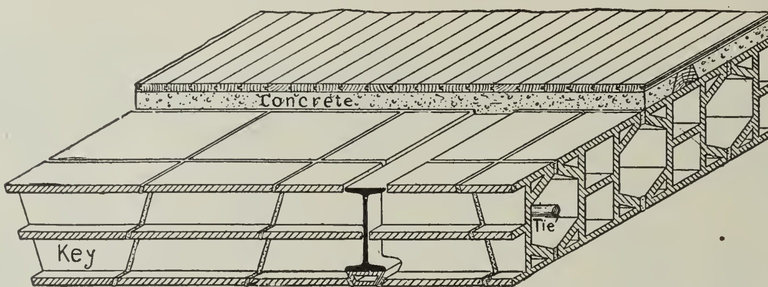


Fig. 326. End-construction, I-beam Shape. End-construction Skew.

there is great waste of mortar. Complaints have been occasionally made by architects that they find it difficult to get a strictly flat ceiling with this type of arch. The open ends of the hollow tiles not being well adapted to receive mortar for the mortar joints, the mortar often squeezes out, permitting some of the blocks to drop below the others.

Advantages.—The principal recommendation for the end-construction is that if the arches are properly set, they will develop about 50 per cent more strength for the same weight than

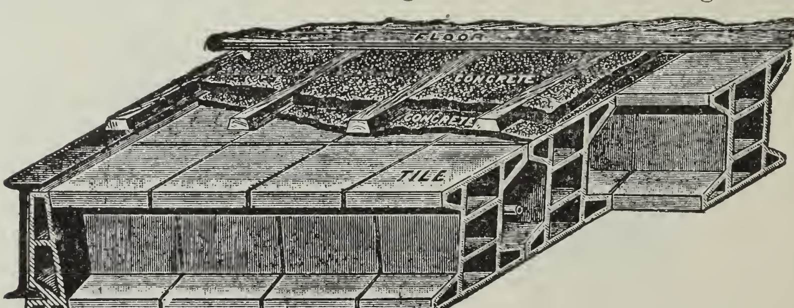


Fig. 327. End-construction, I-beam Shape. Side-construction Skew.

results from the side-construction. This has been demonstrated by theory and verified by tests. The advantages of reduced weight with equal strength, and the generally smaller amount of cutting for tie-rods, have already been referred to.

Materials Used.—The materials generally used for this type of

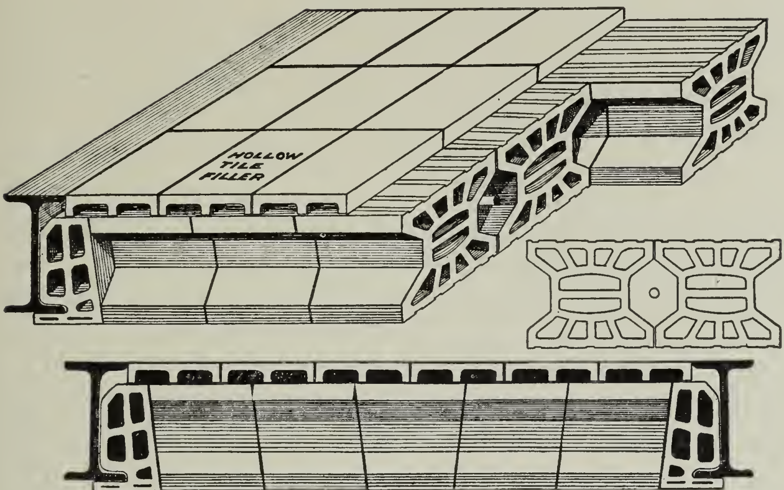


Fig. 328. End-construction, I-beam Shape. End-construction Skew.

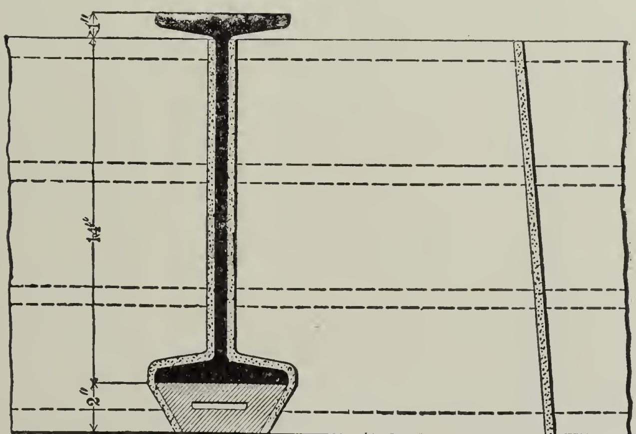


Fig. 329. End-construction Detail. Skew-back and Beam Flange Covering.

construction are porous and semi-porous tile. The companies manufacturing the patented types like the "Excelsior" arch, shown in Fig. 328, use semi-porous tile for these forms.

Shapes and Sizes of Intermediate Blocks.—The shape of the blocks in the ordinary end-construction is approximately rectangular, with depths ranging from 6 to 15 inches, and lengths and widths usually 12 inches, although they may be varied.

Webs and Voids.—The thickness of webs in semi-porous tile, end-construction, should be not less than ½ of an inch, and in porous tile not less than ¾ of an inch. Increased thickness of web increases the fire-resistance as well as the strength.

In regard to the number of webs or partitions, it may be said that it varies with the size of the block and the weights to be sustained. For blocks 6 inches, 7 inches and 8 inches deep, one horizontal web and two vertical webs are used. A block only 8 inches wide would have one horizontal and one vertical web. Ten-inch and 12-inch arch blocks are made with one or two horizontal webs; and blocks deeper than 12 inches, with not less than two horizontal webs. Voids are made about 3 inches square in blocks required for the greatest strength.

Joints.—The arch blocks must be set end to end in straight courses from beam to beam, and cannot be set breaking joint as in the side-construction method. As there is no bond between the rows of tiles, if a single tile in a row is broken or knocked out of place, the entire row is likely to fall; and for the same reason a single tile cannot be omitted in order to make a temporary hole, as it can be in side-construction arches. As shown in the figures, the end joints are always bevelled, with the ends of the blocks parallel. This allows all intermediate blocks, or lengtheners, to be made with the same die.

Keys.—The length of key required is the principal deciding factor in the choice of the type of keys for end-construction arches. Both end-construction and side-construction keys are used. When, with standard lengtheners, a key is needed 6 inches or more in length, end-construction keys are generally put in; while for shorter key-spaces, side-construction keys are generally but not always used. A ⅞-inch fire-clay slab is frequently inserted between the ends of the tiles, with the end-construction keys. In the case of either type

of key the horizontal webs should be in line with those of the lengtheners.

Skew-backs.—Skew-backs may be "flat," as shown in Figs. 323, 324, 325, 326, 329, etc., or "raised," as shown in Figs. 330, 332, etc., and they may be the end-construction or the side-construction, as illustrated in the different figures. Figs. 323, 325, 326 and 329 show end-construction skews, with simple notches cut in the ends for the bottom flanges of the beams. Figs. 324, 327 and 328 show side-construction flat skews.

Although end-construction skew-backs are stronger than those of side-construction, the latter are generally considered better for practical use; and when they are made with the horizontal webs amply strong and running in the general direction of the thrust-lines of the arch, they develop the necessary strength. The reasons the end-construction skews are not so practical and convenient to use are that much mortar is lost in the voids, an even bearing is secured with difficulty and the protection against fire for the beams or girders is not as good as in the case of the side-construction skews.

In case very deep beams are used, such as 18-, 20- and 24-inch beams, either a considerable space must be filled in above floor arches, or raised skew-backs must be used. The latter method is generally preferable, and it is a method that is employed for roof arches also, where the arch tops are usually level with the tops of the roof beams, and the light roof weights require arches of smaller depth than that of the beams. Figs. 330, 331 and 332 show types of side-construction raised skew-backs for end-construction arches. Raised skews are generally made in this way. Fig. 331 shows some variations in details of construction.

The use of raised skew-backs prevents the formation of flat ceilings, unless a special and expensive construction is added. Panelled ceilings result, the encased beams or girders appearing below the ceiling surface; and entirely aside from questions of design, they are not as desirable as flat ceilings, as they do not reflect the light as well, and as they increase the area exposed to fire and form pockets for heat and flame.

Spans, Depths, Weights and Safe Loads.—For complete data regarding these, the reader is referred to the manufacturers' handbook and to Kidder's "Architect's and Builder's Pocket-Book." About 5 feet or 6 feet are the commonest arch spans, and 10-inch

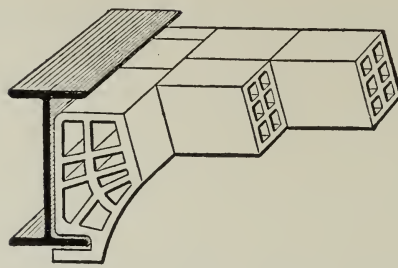


Fig. 330. End-construction, Raised Side-construction Skew-back.

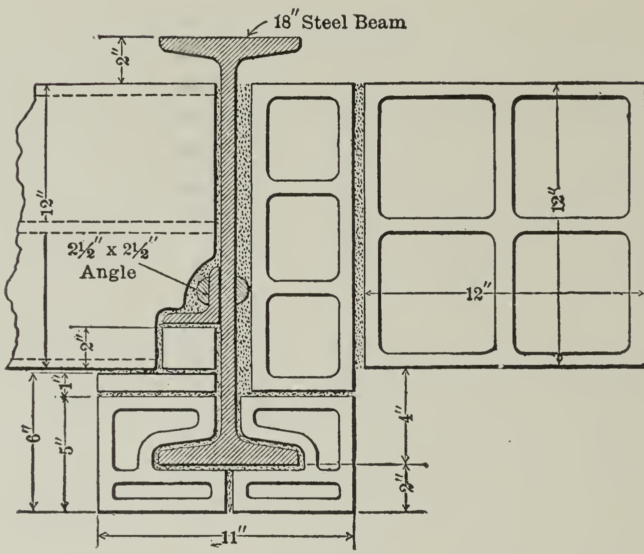


Fig. 331. Details of Raised Arches, Skews and Flange Covering.

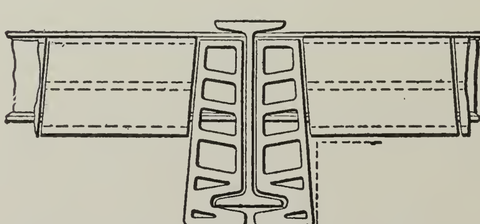


Fig. 332. End-construction, with Side Raised Skew-back Beam Covering.

blocks with 10-inch I-beams the combinations most frequently used. It is better, and about as cheap, to have the depth of arch and beam the same.

On account of differences in materials and thicknesses of webs, manufacturers do not agree regarding weights of similar floor blocks.

Tables of strength cannot be made which will apply to all flat

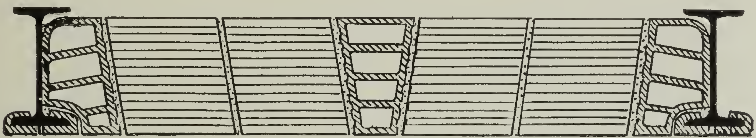


Fig. 333 Combination Side-and-end-construction Arch.

arches of hollow tile, as safe loads depend upon span, depth, sectional area per lineal foot of arch, and ultimate strength of the material used; and the last two conditions vary with the products of different manufacturers.

434. *b.* 4. FLAT TILE FLOOR ARCHES. COMBINATION SIDE-AND-END CONSTRUCTION.—There are several styles of combination arches now manufactured. The object of making this shape of arch, as has already been mentioned, is to obtain the strength of the end-construction and at the same time get a flat bearing for the skew-backs. Figs. 333 and 334 show floor arches of combination side-and-end-construction.

435. *b.* 5. FLAT FLOOR-BLOCK OR LINTEL CONSTRUCTION.—Attempts have been made at different times to

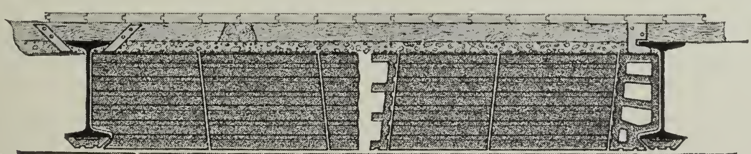


Fig. 334. Combination Side-and-end-construction Arch.

construct floors of single terra-cotta blocks or lintels without reinforcement, spanning from one beam to another in single pieces and covered with concrete. The low maximum limit of tile span, however, and the resulting large number of steel beams required, make the cost of such systems too high to be considered.

The Fawcett ventilated fire-proof floor, at one time used quite

extensively, but now discontinued in the United States, was constructed on this principle.

The National Fire-proofing Company for some years made a floor tile which was intended to be used to span from beam to beam when the spacing between the beams did not exceed 3 feet; but the manufacture of these tiles has been discontinued.

Fig. 335 shows a type of arch introduced by Henry Maurer & Son, called the "Eureka" arch, and consisting only of two skew-backs and one center or "key-tile" set between them. They are still made (1908) for use in light work, and the manufacturers claim they may be used to advantage in dwellings and apartment-houses where the loads to be supported are almost nominal and the spans do not usually exceed 16 feet. Under such conditions this floor arch can be quickly and cheaply erected, as no centering is required and no concrete filling except a little light filling between the nailing-strips. But this construction requires a uniform spacing of 30 inches between centers of I-beams, and cannot be used to advantage with

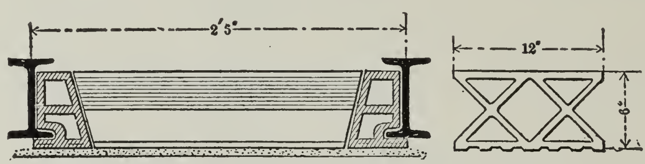


Fig. 335. Eureka Three-block Floor Arch.

beams deeper than 6 inches. The entire floor construction will weigh about 44 pounds per square foot when 6-inch steel beams and single ⅞-inch flooring are used.

436. *b*. 6. FLAT TILE FLOOR CONSTRUCTION, REINFORCED.—*General Description.* The principle of reinforcement of one material with another, now so generally in use in reinforced concrete construction, has been applied to terra-cotta or tile fireproof floor construction in an attempt to reduce, for the shorter spans, the arch-block depths, or to adapt the flat arch to wide spans.

The advantage of this system is a greater strength for the same weight per square foot than with reinforced concrete construction, due to the disposition of the material around voids, and to the greater depth. The disadvantage is a greater expense than for cinder concrete, due both to the actual cost of the materials used in the floors and to the fact that there is more building as a whole because of the increased total height caused by thicker floors.

Different Types. There are several different types of reinforced flat tile floor construction, and three of them will be briefly mentioned and illustrated,

1. The "New York" Reinforced Terra-cotta Flat Floor Arch (Bevier patent).

2. The "Johnson" Long Span Reinforced Terra-cotta Flat Floor Arch.

3. The "Herculean" Reinforced Terra-cotta Flat Floor Arch.

1. *The "New York" Floor Arch.* Figs. 336 to 340 show details of construction, shape of blocks, reinforcement, etc. The arch was designed by Mr. P. H. Bevier, of the New York branch of the National Fire-proofing Co. The following briefly but sufficiently explains the construction, and is condensed and quoted by permission from this company's explanation of it.

"This arch was designed for use where a light and cheap but strong floor construction with a flat ceiling is required, and is particularly adapted to wide spans in shallow beams. Where light floor construction with deep beams is necessary it can be secured by setting the blocks level with the top of the beams and using a flat metal lath ceiling, or by omitting the ceiling a panelled effect is obtained.

"Where shallow beams are used the blocks are set level and one inch below the bottom of the beams. Light cinder concrete or dry cinders is used to level up to the top of the beams.

"The wire truss reinforcement [Fig. 339] used in this system is shipped to the building in reels, and is cut to proper lengths on the job as required. It is imbedded in Portland cement mortar, between the blocks, where it is protected from the heat in case of fire. The open-work construction of the wire truss enables the mortar to flow freely all about it and the joint can be thoroughly filled between the blocks and the wire perfectly imbedded.

"The 6-inch arch for 6-foot span and 8-inch arch for 7-foot 6-inch span have been tested by the Bureau of Buildings of New York and accepted for a live load of 150 pounds per square foot.

"The 'New York Arch' has been successfully used in a number of large buildings in New York."

Load tests were made to determine the ultimate strength of the 6-inch arch on a 6-feet span, and it was found to be 1,600 pounds per square foot.

Fig. 336 shows a perspective of a typical "New York" arch, with reinforcement, the "soffit skew" showing on the left and the "plain skew" on the right.

Fig. 337 shows two sections of raised "New York" arches in deep beams, one figure showing a panelled ceiling and one showing a metal lath and plaster ceiling. A photograph of a "beam-block" for this construction is also shown.

Fig. 338 shows sections through an arch parallel to the beams, one through a 6-inch arch and one through an 8-inch arch.

Fig. 339 shows the wire truss reinforcement.

Fig. 340 shows a section through a wide span arch, employing more than one wire truss to give greater tensile strength at the bottom of the middle part of the arch. The ends of some members are turned up to strengthen the end blocks and to prevent failure by shearing. The depth of blocks, number of trusses and size of wires are proportioned to the load and span.

For total weights of typical floors, see the full data with descriptive illustrations in the manufacturers' catalogues and hand-books.

2. *The "Johnson" Floor Arch.* Figs. 341, 342 and 343 show the general method of construction of this system. It was invented by Mr. E. V. Johnson, and is now controlled by the National Fireproofing Company. Among the buildings using it may be mentioned the post-office building in Chicago. The basis of this flooring consists of large steel wires transversely interwoven with still larger wires spaced, on an average, 4 inches apart. These latter run straight from bearing to bearing. A woven metal fabric also is often used. Over and through the wires or metal fabric is placed rich Portland cement mortar which supports and unites the tiles, tending to make a monolithic construction. A temporary flat centering has to be first erected in making these floors.

This system does away with the necessity for steel beams, saving weight and expense, and making a floor that stretches from girder to girder or from wall to wall. It may be used with spans up to 25 feet, 16 feet being the most advantageous span.

The tiles vary from 3 to 12 inches in depth, and are laid in mortar in continuous rows, breaking joint as shown in Fig. 341, and having the ends square to the beds. Usually a 2-inch layer of concrete is spread over the tops of the tiles.

The fire-resisting qualities of this type of floor construction may

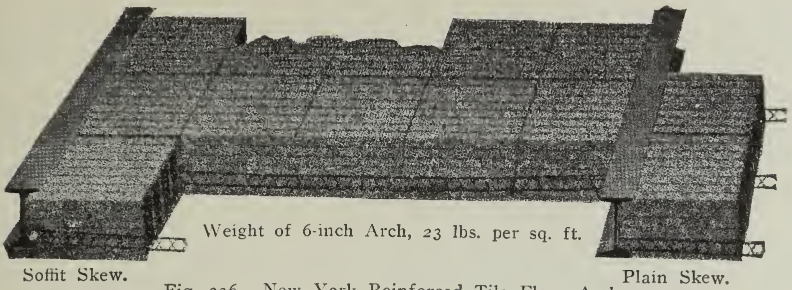


Fig. 336. New York Reinforced Tile Floor Arch.

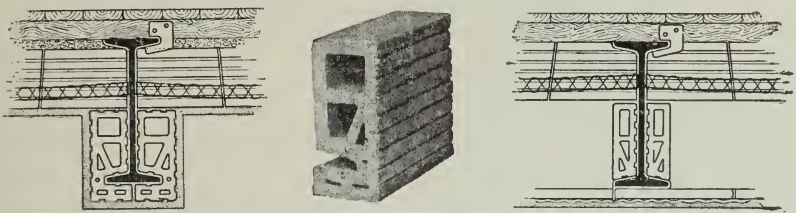


Fig. 337. Beam Block and Sections of New York Arch.

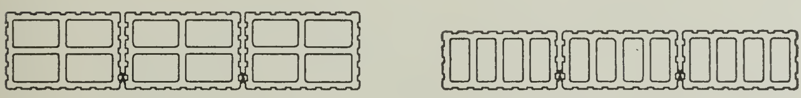


Fig. 338. Sections Through New York Arch Parallel to Beams.

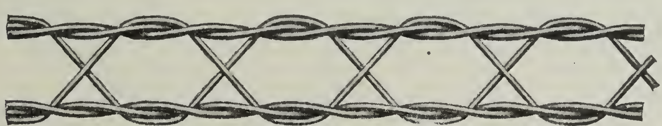


Fig. 339. Wire Reinforcement of New York Arch.

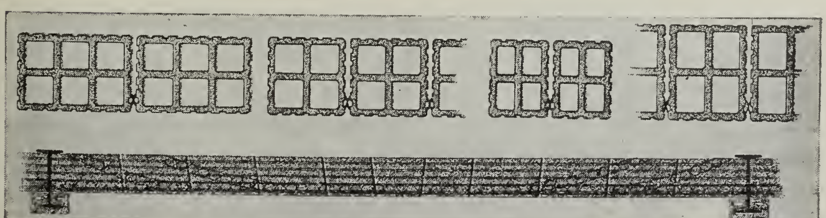


Fig. 340. New York Wide Span Double Trussed Arch.

be said to depend upon the concrete rather than upon the tiles; but the results of tests show a perfect adhesion of the mortar and a powerful resistance to high temperatures without injury.

The strength of the construction depends upon the reinforcement and the adhesion of tile, steel and cement mortar. Details of different weights per square foot, both with and without the cement on the top of the tiles, and for varying depths of tiles, are given in the hand-books, where there may also be found tables of the ultimate strength of the floors for different spans and for different

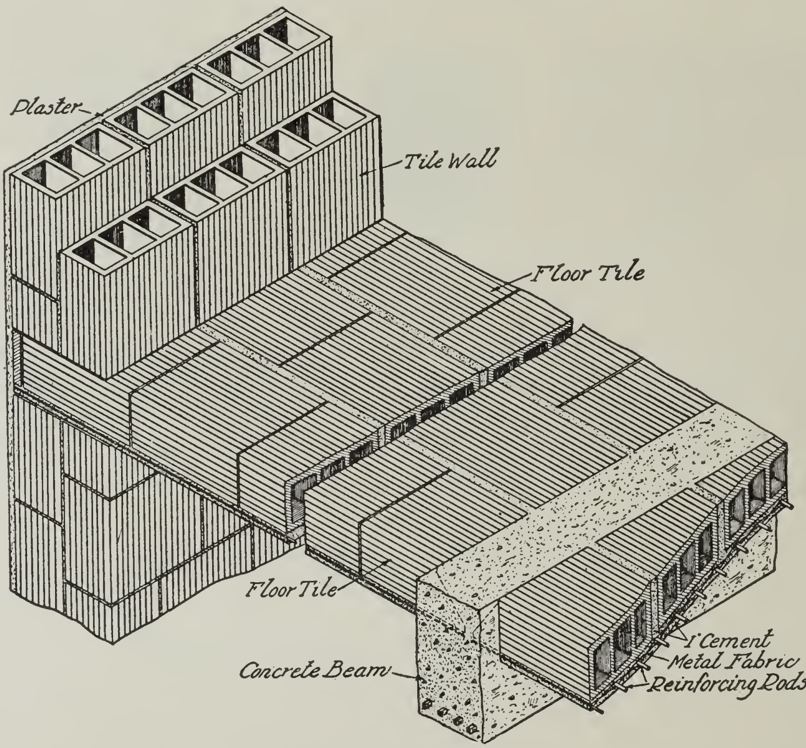


Fig. 341. Johnson System of Floor Construction.

thicknesses of tiles, with the proper factors of safety to be used for various kinds of buildings.

As an indication of the strength and stiffness of floors of this type, the result of the following test is given: A uniformly distributed load of 187,680 lbs., or 733 lbs. per square foot, was placed on a portion of this flooring, 16 feet square, supported by walls on the four sides. The deflection of the floor under this load

was slightly over ¼ of an inch, and with the load reduced to one half the above, the deflection was slightly less than ⅛ of an inch.

Fig. 341 shows a perspective view of the general construction, with the metal fabric. The rods are put in place as the fabric is used. Fig. 342 shows an end view, and Fig. 343 a side view, in

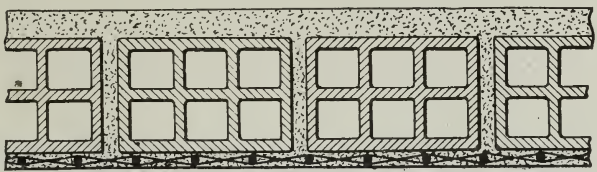


Fig. 342. Johnson Floor Arch. End View.

section, of this construction, including fabric, rods and concrete covering on top of the tiles.

3. *The "Herculean" Floor Arch.* Figs. 344, 345, 346 and 347 show the general construction of this form of floor arch. It was patented by Henry Maurer & Son, in 1898 and 1900, and is manufactured by them.

This form of arch is well adapted to large spans, up to 22 feet, eliminating entirely the use of steel beams. The material used is semi-porous terra-cotta. The only metal employed is T-iron, thoroughly imbedded in Portland cement mortar to prevent corrosion; and as a further protection the metal is covered by not less than 2 inches of terra-cotta.

An arch measuring 18 feet from wall to wall, loaded with

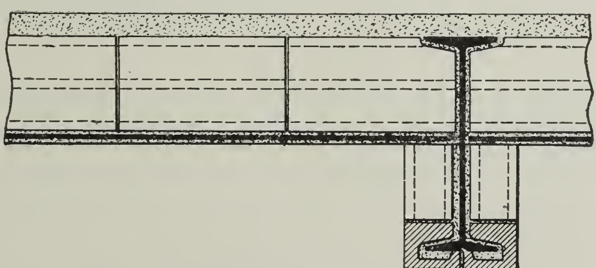


Fig. 343. Johnson Floor Arch. Side View.

108,000 pounds of hard bricks distributed over a surface of 180 square feet (600 pounds to the square foot), and left standing for three weeks, showed no perceptible deflection.

The blocks are 12 inches by 12 inches on top and vary in depth from 8 to 12 inches, as required. There are grooves in the sides of

the blocks to accommodate the T-bars, which are 1½ by 1½ by $\frac{3}{16}$ inches in their dimensions, and which extend the full length of the span. The blocks break joint in plan, are filled with cement mortar and have a bearing of from 4 to 6 inches on the walls or girders.

The system possesses good fire-proofing qualities, the steel tension members being well protected against fire by an ample thickness of terra-cotta.

Some of the advantages claimed for this construction are its low cost compared with floors of equal fire-resisting qualities, and of a design requiring steel beams every 6 or 8 feet; its ready adaptation to buildings with masonry walls and partitions and with little structural steel; its unusually smooth undersurface or ceiling, resulting in a reduced cost of plastering; and its erection without tie-rods.

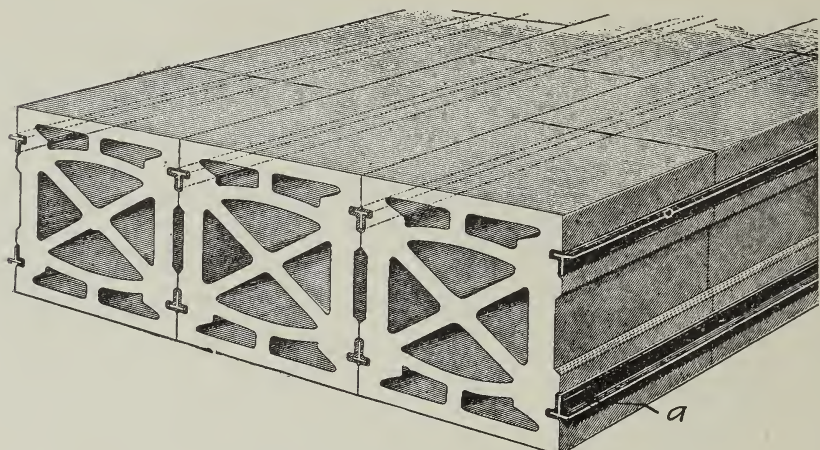


Fig. 344. Herculean Floor Arch.

Fig. 344 shows in perspective a portion of this arch, showing a late improved form of blocks, with the reinforcing T-bars in place.

Fig. 345 shows a 10-inch arch, of span over 20 feet, resting on an outer wall and on a 2-feet plate-girder, the sides and lower flanges of which are fire-proofed with hollow tile blocks. Owing to the extended span, over 20 feet, and the elimination of beams, heavier girders become necessary to sustain the loads. By using "shoe-tiles" and blocks as shown, the arch is raised nearly to the floor level and needs but little concrete filling.

Fig. 346 shows arches resting on two 18-inch girders, and arches

resting on one 18-inch girder, the girders being fire-proofed as shown.

Fig. 347 shows an arch resting on I-beams, for use in dwellings and other structures in which a flat ceiling is wanted. The blocks adjoining the I-beams are cut to drop below them so as to receive the soffit tiles and thereby fire-proof the bottom flanges. As the

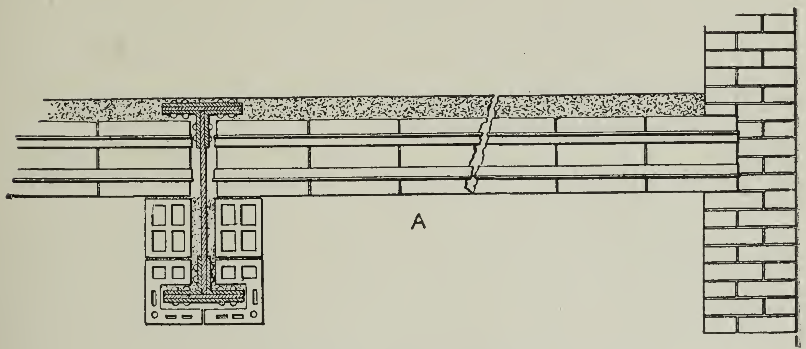


Fig. 345. Herculean Floor Arch and Girder Covering.

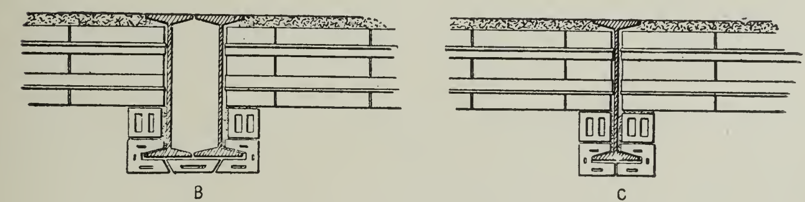


Fig. 346. Herculean Floor Arch and I-beam Covering.

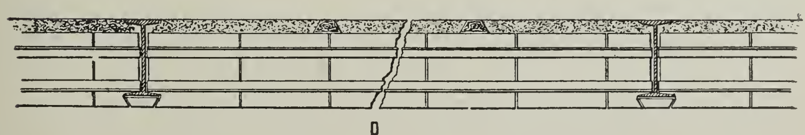


Fig. 347. Herculean Floor Arch and Beam Covering.

arch comes nearly to the tops of the beams, it is only necessary to put on sufficient concrete to imbed the floor sleepers.

437. *b.* 7. THE GUASTAVINO TILE ARCH, VAULT AND DOME CONSTRUCTION.—

General Construction.—This is a method of constructing light, strong, fire-proof masonry, domes, vaulted ceilings, floors, etc., by

means of hard-burned, semi-porous terra-cotta slabs, 1 inch in thickness, about 6 inches in width and from 12 to 24 inches in length, laid so as to break joint in successive layers and all bonded together in Portland cement mortar so as to make one solid mass. It was devised by the R. Guastavino Company, of New York and Boston.

The floors in this system are built by spanning the space between the girders with a single arch, vault, or dome, constituted of two, three or more thicknesses of these 1-inch tiles, depending upon the dimensions of the arch, vault or dome. In its best application, steel is used in tension only, as tie-members, and, in place of steel girders, tile girders are constructed of the latter material. Wherever steel is used it is imbedded in the masonry construction.

Examples.—One of the earliest notable buildings using this system of construction is the Boston Public Library, erected in 1892; and some of the later important constructions following this are the Hall of Fame and the Library building of the University of New York and the Metropolitan Museum of Art, New York; the Massachusetts Horticultural building, the American Type Foundry building, and the Massachusetts General Hospital, Boston; and the Minnesota State Capitol building, St. Paul, Minn.

The floor above the crypt of the Cathedral of St. John the Divine, in New York, measuring 56 by 60 feet, with no interior supports, and designed to carry a safe load of 400 pounds per square foot, is constructed on this principle, and is an example of wide-span arching.

Whenever a vaulted ceiling is desired this seems to be the best system of construction yet devised.

Strength.—Floors built on this principle have been tested under the supervision of the New York Building Department up to 3,700 pounds per square foot, with spans of 10 feet.

When used between I-beams the only steel beams required are those spanning from column to column.

Architects contemplating the use of this system of construction are advised to consult the R. Guastavino Company before letting any contracts.

Cost.—Wherever vaulted ceilings are required this construction is as cheap or cheaper than any other form of equally fire-proof construction. One particular advantage of this system is the possi-

bility of making one course of tile of pressed or glazed material, thus obtaining a most effective and permanent finish, as in the case of the City Hall station of the New York Subway, which is constructed for very heavy loads without the use of steel.

Advantages.—The advantage over concrete of this masonry vaulting for domes is that it is self-supporting during construction; and the lumber used consists of light pieces only, which, as skeleton templates, serve principally to give the curve required. In concrete work, owing to the immense weight of the mass to be supported until it sets, and to the necessity of building up the forms solidly with heavy timber, an enormous amount of timber and planking is required; and the expansion and contraction of this material, due to the absorption of water and the drying out, frequently cause cracking and other defects in the concrete shells. The Guastavino construction being self-supporting during erection, is free from these disadvantages, and naturally commends itself for large spans where strength, durability, architectural beauty and design, combined with lightness and stability, are essential features.

Recent Typical Large Domes.—The following are some typical large domes erected with the Guastavino tile arch construction:

New Custom House, New York; elliptical dome, major axis, 130 feet.

New Girard Trust Company's building, Philadelphia; hemispherical dome, 101 feet in diameter.

Rodef Sholem Synagogue, Pittsburg, Pa.; quadrangular dome, 92 feet in diameter.

Library building, University of New York; dome, 90 feet in diameter.

Rotunda, University of Virginia; dome, 69 feet in diameter.

Hall of Sciences, Brooklyn, N. Y.; dome, 60 feet in diameter.

Bank of Montreal, Montreal, Can.; dome, 72 feet in diameter.

Grace Universalist Church, Lowell, Mass.; dome, 70 feet in diameter.

McKinley Memorial, Cleveland, Ohio; dome, 58 feet in diameter.

Minnesota State Capitol, St. Paul, Minn.; dome, 60 feet in diameter.

On some of the above domes, such as that of the Girard Trust Company's building and of the McKinley Memorial, a heavy stone exterior finish, several inches in thickness, has been applied directly;

in other instances, such as in the 54-feet diameter dome of the Columbia University Chapel, New York, and in the 52-feet diameter dome of the Madison Square Presbyterian Church, New York, porous tiles are used for the exterior constructive course, to which the finishing tile or copper is attached by nailing.

2. *c*. CONCRETE FLOOR ARCH CONSTRUCTION.

438. GENERAL CONSIDERATIONS.—Having considered, in fire-proof floor construction, the use of tile or terra-cotta, employed both alone and with reinforcing metal, there remains to be briefly discussed the very important and useful fire-proof floor construction, employing reinforced concrete for its materials. The concrete may be used without the reinforcement, but such construction is not practicable for any but very short spans because of its necessarily great thickness and weight and consequent expense.

Concrete and reinforced concrete floor construction will be considered here, reinforced concrete construction in general being discussed in the chapter devoted to that subject.

Advantages.—The principal advantages claimed for reinforced concrete floor construction over tile construction may be enumerated as follows:

1. Great adaptability to irregular framing and connections.

2. Rapidity of construction.

3. Generally but not universally smaller weights per square foot of floor.

4. Economy, considering the total cost of the steel frame and the floor systems themselves.

Disadvantages.—The principal disadvantages are:

1. More or less interference with the progress of other parts of the work.

2. Frequent long delays in proceeding with other interior work and finishings after floors are put in, caused by slowness in drying out.

3. Delays in installation on account of cold weather.

4. Greater chances of poor construction on account of inferior work and manipulation of materials by unskilled labor.

It is the opinion of the writer that from what is known at the present time, it cannot be said that either kind of floor construction is very much better or worse than the other. Either cinder con-

crete or tile fire-proofing will probably stand any test of fire to which it is likely to be subjected, if the workmanship and materials are of the very best. Artificial tests of any system are almost invariably successful because the arches are always built of the best materials of their respective kinds and in the best possible manner.

In examinations of the effects of great heat upon different building materials in the recent great conflagrations, advocates of both kinds of fire-proof floor construction have often undoubtedly found what they looked for.

It may be said that there have not been as many tests in great fires of concrete construction as of brick, terra-cotta and tile, all unquestionably splendid fire-proofing materials; but it must also be admitted that the enormous amount of concrete construction now under way in all parts of the world where building operations are carried on implies great confidence on the part of architects and engineers in its efficiency in many kinds of structures.

439. THE COMPOSITION OF CONCRETE.—The materials used in making concrete of various kinds, with their proportions, and with data regarding other details belonging to concrete mixing, and putting in place, etc., are discussed in Chapter X, on "Concrete and Reinforced Concrete Construction."

440. DIFFERENT FORMS AND METHODS OF REINFORCEMENT.—The discussion of the principal types of the many shapes of reinforcing metals also is taken up in Chapter X. While many of these different types are used in concrete floor construction, there are still other types of metal reinforcing used in floors, but not so well adapted to concrete beams or girders. These latter forms will be briefly mentioned in the present division of the subject in connection with the different types of reinforced concrete floor construction.

Rods and Bars versus Wire Fabrics.—Both types are used and good results are obtained from each. The theory of reinforced concrete beams and slabs, however, would seem to indicate round or square bars, plain or deformed, from ½ to ¾ of an inch in size, and properly spaced as required for the varying loads and spans, as the ideal reinforcement for fire-proof floors. The number and size of the bars should be such that, within certain limits, the adhesion between steel and concrete will be a maximum.

While wire fabric reinforcements have certain advantages, they

have also the disadvantage of greater liability to corrode, on account of the smaller sections. They also lend themselves more readily to a displacement during the putting in place of the concrete, possibly moving too high to strengthen the floor as required, or falling too low and becoming exposed to corrosion or fire.

Position and Direction of Reinforcement.—As the function of the reinforcing metal is to take up the tensional stresses, it is placed, in floor arch construction, near the lower surface of the floor slabs.

The transverse reinforcing bars or wire strands are stressed when the floor loads are uniformly distributed and the longitudinal reinforcing bars when the loads are concentrated. Both should be put in. With reinforcement in the form of vertical bars, the latter often tend to shear through the concrete when the floors are heavy.

Types of Reinforced Concrete Floor Arch Construction.—Three general types of this construction will be considered:

1. Segmental Concrete Floor Construction.
2. Flat Concrete Floor Construction.
3. Sectional Concrete Floor Construction.

c. 1. SEGMENTAL CONCRETE FLOOR ARCHES.

441. GENERAL DESCRIPTION.—When concrete is so disposed that it acts almost entirely in compression, it is in the best form to resist stresses; and consequently the arched form is better than the flat form for floor construction, especially in those buildings in which the floor loads are very heavy, and in which a flat ceiling is not necessary.

These arched concrete floor systems are put in place with various modifications of details, the reinforcing consisting of rods, bars, tees, channels and different kinds of netting and wire fabric, when wide spans require them. Tie-rods are required in all cases.

The patents taken out for several arched concrete systems are mainly for those details which are connected with the putting of the work in place, the use of which often leads to greater convenience and economy in installation.

For data regarding the strength of concrete floor arches for spans over 5 feet, both plain and with different forms of reinforcement, and also regarding their strength when compared with that of arches of other fire-resisting materials, the reader is referred to Kidder's "Architect's and Builder's Pocket-Book," Chapter XXIII,

which contains a condensed account of the celebrated "Austrian Experiments" on these floor arches. The two following general statements may be made, however, regarding their strength, when their spans are 5 feet or less, and when there is no reinforcement:

(1) When made of gravel-concrete of a 1 to 6 mixture, and with a thickness of 3 inches at the crown, a floor arch should sustain, without cracking, a uniformly distributed load of 1,500 pounds per square foot.

(2) When made of cinder-concrete, floor arches are inferior to those made of gravel-concrete in strength only. The thickness at the crown should be not less than 4 inches, and the rise at least one-eighth of the span. Such an arch has approximately the same strength as a segmental tile 6-inch arch of the same span.

442. THE ROEBLING CONCRETE FLOOR ARCH SYSTEM.—Figs. 348 to 351 show the general construction of the various types of the concrete arch floor system of the Roebling Construction Company. This system has been used in many buildings and is very strong; and it is also eminently fire-resisting when the type used includes the thorough protection of the bottoms of the steel beams as shown in the illustrations.

In this system no wood centers are required, as the arched wire lathing with its interwoven steel rods itself forms the permanent centering; and as this wire centering is made at the factory to readily fit into place, and is arched in advance of the concrete work, the latter progresses rapidly and continuously. This centering will hold a considerable load itself, and is looked upon as a sort of safeguard in the case of accidents, such as the falling of a workman. It is also preferable to wood centering in permitting any excess of water to drip down from the fresh concrete.

The Roebling Construction Company furnishes tables giving all required data for different spans and types of construction, such as maximum allowable spacing of steel beams, total levels of concrete at spring of arch, thickness of concrete in middle part of arch, weight per square foot, safe loads, etc.

The average safe loads with a liberal factor of safety may be taken at from 800 to 1,000 lbs. per square foot, when the spans are between 5 and 6 feet. The figures show the usual average maximum spans desirable for the different types. The thickness at the crown is usually 3 inches. In types 1, 2 and 3, Figs. 348, 349 and

351, the clear rise of the arch is usually made 1½ inches to each foot of span. For a 14-feet span with 18-inch I-beams, the rise has been made about 14 inches, and for an 18-feet span, also with 18-inch I-beams, the rise has been made 16 inches. The depth of the concrete arch at the haunches becomes correspondingly greater with the increased width of the spans.

Fig. 348 shows System A, Type 1, of the Roebling floor arch system. A 6-feet span is the maximum recommended. The ceiling construction and the method of fire-proofing the columns and girders are also shown. This type is recommended by the manufacturers for public buildings, offices, theatres, hotels, schools, churches, banks, libraries, hospitals, residences, etc.

Fig. 349 shows System A, Type 2, in which the maximum spans desirable are 6 feet 6 inches or 7 feet, and which is called the "Warehouse" Construction. It is adapted also to factories, stores, freight depots, breweries, etc. The flat ceiling is omitted, and the soffits of the beams and girders are well protected with concrete in the rounded form shown.

Fig. 350 shows a variation of System A, Type 2, with a recommended maximum span of 5 feet. The flat ceiling is omitted here also. When the beams are spaced not too far apart, and when no piping is to be placed transversely over them, the floor strips or sleepers may be depressed below the top flanges, reducing the total depth of the floor by the depth of the sleepers.

System A, Type 3, is quite similar to Type 2, the difference being an added suspended flat ceiling which may be fixed below the beams at any distance desired, in order to allow for piping, etc.

Fig. 351 shows System A, Type 4. It is used where the beams or supports are more than 10 feet apart, and has been installed with success in spans up to 18 feet. This type is similar to the others, except that curved T-section ribs are used instead of the solid steel rods, in the arch wire. The T's are of suitable sectional area to support the loads, and are spaced 2 feet apart and held rigidly in position by means of steel spacers. The wire lath is then laid between the T's and laced to them, and on this permanent centering the concrete is laid in the usual manner.

443. THE RAPP T-RIB, BRICK AND CONCRETE FLOOR ARCH SYSTEM.—Figs. 352 and 353 show the general type of construction of this system, which combines the strength of the

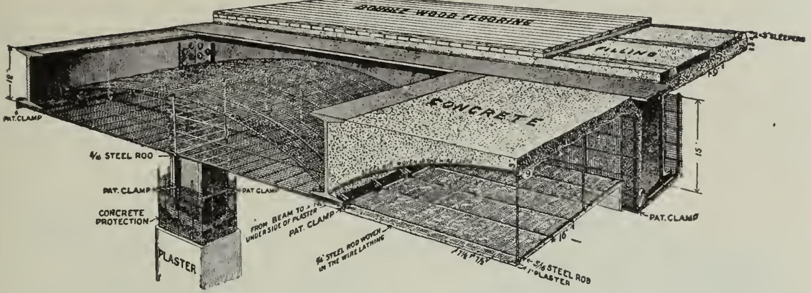


Fig. 348. Roebling Arch, System A. Type 1.

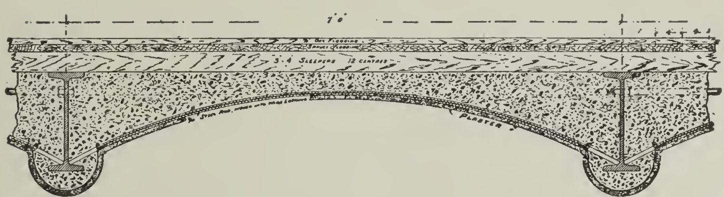


Fig. 349. Roebling Arch, System A. Type 2.

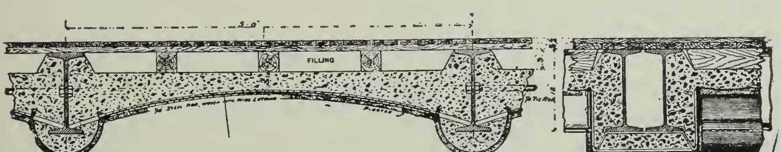


Fig. 350. Roebling Arch, System A. Type 2. Sleepers Depressed.

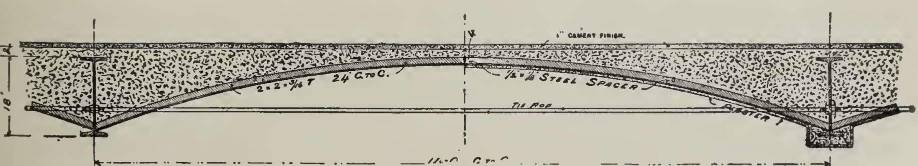


Fig. 351. Roebling Arch, System A. Type 4.

ordinary row-lock brick arch with that of the steel T-ribs. A cinder concrete filling in the form of an arch is placed above the brick and T-rib construction. The system can be installed with rapidity, in a continuous operation, and no wood centering is required, the T's serving as a centering. By special arrangement

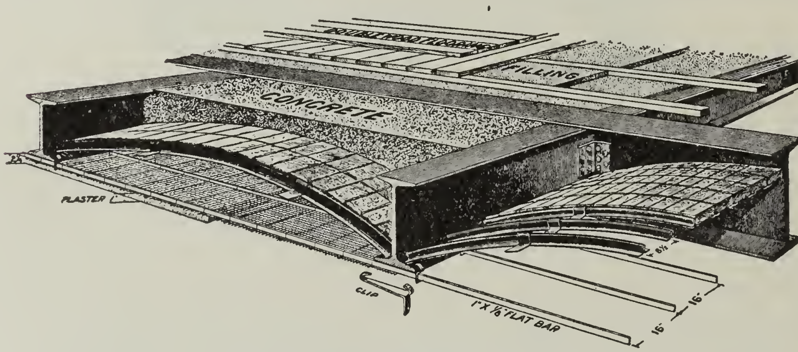


Fig. 352. Rapp System. Type A.

the Rapp Fire-proofing Company uses the Roebling patent wire lath ceiling construction whenever flat ceilings are required.

There are three types of this system. Fig. 352 shows Type A in which the bricks are laid flat side down. The T's abut against the seat formed by the web and lower flange of the steel floor beams, and are held in place by steel separators. A 2-inch thick segmental common brick arch is then formed by laying the bricks flat between the T's which are set about 8½ inches on centers. The usual cin-

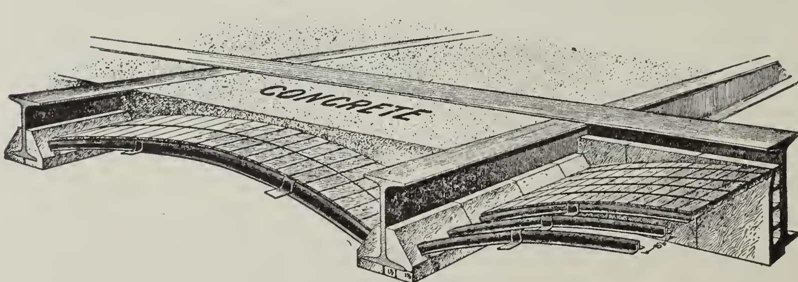


Fig. 353. Rapp System. Type C.

der concrete filling, in the form of a segmental arch, is then put in over the brick and T-rib construction. In spans up to 10 feet, the average ultimate strength for a distributed load is 3,000 pounds per square foot.

The flat ceiling construction shown is the Roebling standard wire lath ceiling.

Type B is similar to Type A, except that the bricks are set on edge. The resulting construction is the same as the usual 4-inch row-lock brick arch, with an additional reinforcing of the T-ribs; and it has approximately double the strength of Type A. It is used in spans up to 12 feet.

Type C shows the Rapp system with a special skew-back and segmental arched flooring without suspended flat ceiling. It is well adapted to factories, warehouses, lofts, depots, etc. The skew-back is made solid and protects the soffit of the steel floor beams. The ceilings may be plastered directly on the under side of floor arches, or the brickwork may be pointed.*

c. 2. FLAT CONCRETE FLOOR CONSTRUCTION, REINFORCED.

444. GENERAL DESCRIPTION.—Flat reinforced concrete floor construction can be considered under two general headings; the systems which are patented and the systems which are based upon the same general principles as the former, but which any one may use.

All of them, patented or unpatented, consist generally of concrete slabs of different thicknesses, set between or on the steel floor beams and reinforced at or near the under surfaces with various steel metal, wire, fabric, bars, rods, lath, sheets, plates, etc., and the general principles are about the same in all.

The character of the ceilings and the amount of fire-resisting filling about the floor system to the under side of the flooring, depend upon the position of the concrete slabs in relation to the top and bottom flanges of the floor beams.

In regard to the thicknesses of these slabs in flat reinforced concrete floor construction, it may be said that they are not generally as deep as the floor beams, and that the minimum thickness is usually put at 3½ inches. A general rule is to make the thickness of the concrete slab not less than ⅝ of an inch for each foot of span. The thicknesses vary with the systems and the forms of reinforcement employed.

Some of the patented systems of flat concrete floor construction will be considered first.

* See Article 448a for White Segmental Floor Arch System.

445. THE COLUMBIAN FLAT CONCRETE FLOOR CONSTRUCTION, REINFORCED.*—Figs. 354 to 361 show the general construction of this system, a flat concrete system, in which the concrete, instead of being supported by wires or netting, is reinforced by ribbed steel bars of various sizes and weights, attached to the supporting beams by stirrup connections, or placed upon either flange of these beams, or framed into them with bolted angle connections.

The ribbed steel reinforcing bars are made in sizes of ⅞, 1, 2,

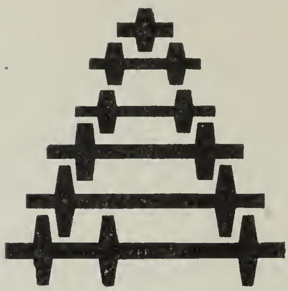


Fig. 354. Columbian System. Ribbed Bars.

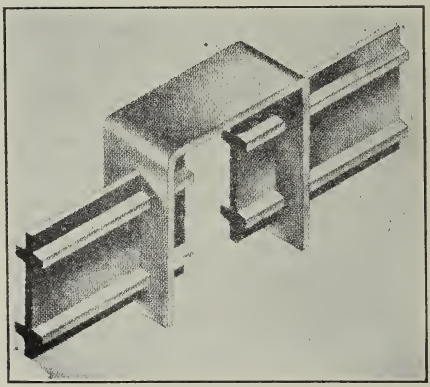


Fig. 355. Columbian System. Steel Stirrup.

2½, 3½, 4¼ and 5 inches in height, most of them being in either heavy or light weight, with section areas varying from .27 of a square inch to 2 square inches, and with weights per lineal foot of from .7 of a lb. to 6.8 pounds. The ⅞-inch and 1-inch bars have one rib, the 5-inch bar has three ribs and the others have two ribs, as shown in Fig. 354.

At the required distance below the tops of the floor beams a temporary wood centering is built, and the bars are imbedded in and entirely surrounded by cinder, slag or stone concrete, of a thickness and mixture determined by the spans, loading and specifications. The beams and girders also are incased with concrete slabs, with insulating air-spaces.

* Patents controlled by the Columbian Fire-proofing Co., of Pittsburg, Pa.

There are two systems of Columbian fire-proof floor construction, viz., the Short Span System and the Long Span System, each system having variations. They are as follows:

COLUMBIAN FLAT CONCRETE CONSTRUCTION.

System	Connections Between Bars and Beams	Standard Relation of Beam and Slab
Short span system A	Stirrups over beams	Top flush with top of beam
Short span system B	Over top flange	Bottom ¾ of an inch below top of beam
Short span system C	Over bottom flange	Bottom 1 inch below bottom of beam
Short span system D	Over concrete beams	Top flush with top or bottom of beam
Long span system A	Stirrups over beams	Top flush with top of beam
Long span system B	Angles and bolts	Top flush with top of beam
Long span system C	Over top flange	Bottom ¾ of an inch below top of beam
Long span system D	Over concrete beams	Top flush with top or bottom of beam

The Systems D in each case above are used when the beam and girder construction or the entire building is of reinforced concrete.

Either a panelled ceiling construction or a flat level ceiling is formed. In case the latter finish is desired, it is obtained as in System C, short span, or constructed independently of the floors with concrete and rods, bars, wire lath or expanded-metal, etc., connected with the lower flanges of the floor beams.

The maximum spacing of the bars is 24 inches. In the short span system three sizes of bars are used, the 1, 2 and 2½-inch bars; and in the long span systems the 3½, 4¼ and 5-inch bars.

The smaller bars for the shorter spans give respectively 3, 3½ and 4 inches of concrete; and the larger bars for the longer spans give respectively 5, 5¾ and 6½ inches of concrete.

The maximum span for short span systems A and B is 12 feet, for short span system C 10 feet, for the long span systems, 20 feet. For the short span systems using 1-inch bars, the most economical spacing of floor beams is usually 6 feet for office-buildings, hotels and apartment-houses, and from 6 to 9 feet for buildings using 2 and 2½-inch bars, in which the floor loads are greater.

In the long span systems the bars are either hung in stirrups especially made, or framed by bolted angle connections to the beam-girders; and in the end spans they are anchored into the walls. In this way floor beams may be omitted between girders, the reinforced monolithic concrete slabs spanning from girder to girder or from girder to walls.

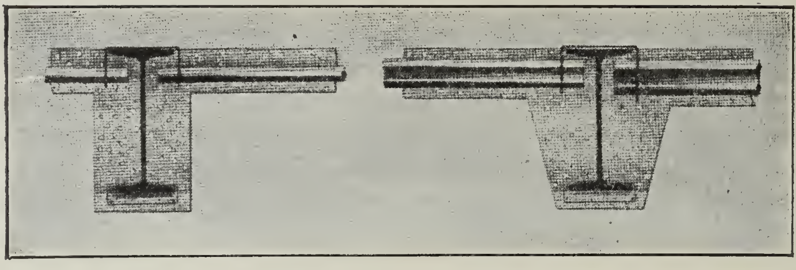


Fig. 356. Columbian System. Short Span. System A.

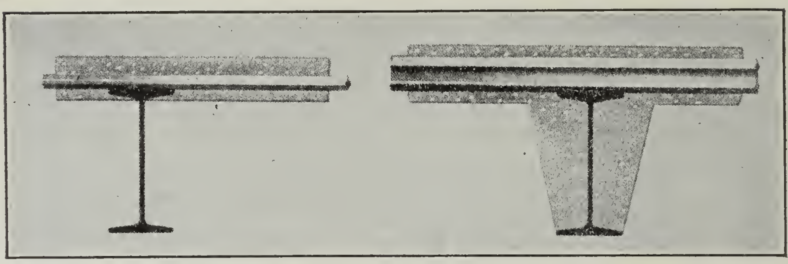


Fig. 357. Columbian System. Short Span. System B.

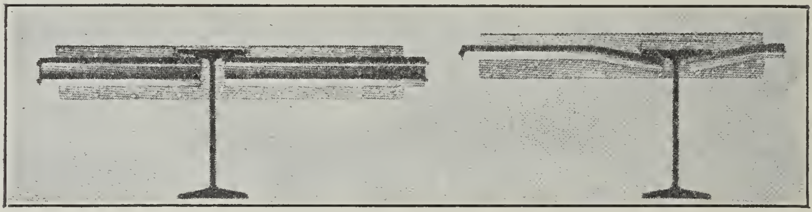


Fig. 358. Columbian System. Short Span. System C.

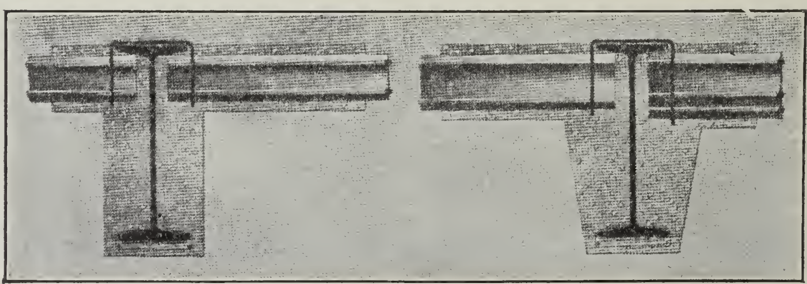


Fig. 359. Columbian System. Long Span. System A.

Nailing-strips are imbedded in the filling, or nailed to the concrete flooring with the filling omitted.

The carrying capacity for these floors is stated in full in the hand-books and catalogues, which give guaranteed safe loads. Overloading causes a gradual bending, and not a sudden failure. The resistance to concentrated loads is great, and the construction is especially strong in resisting drop or jarring loads.

Fig. 354 shows sections of the different ribbed bars.

Fig. 355 shows the steel stirrup for the two-ribbed bars.

Fig. 356 shows sections of short span system A, suitable for 1-inch, 2-inch and 2½-inch bar floors, with stirrups over beams and top of slabs flush with top of beams.

Fig. 357 shows sections of short span system B, suitable for 1-inch, 2-inch and 2½-inch bar floors. Bars continuous over tops of beams, and bottom of slabs ¾ inch below tops of beams.

Fig. 358 shows short span system C, suitable for 1-inch and 2-inch bar floors. Ribbed bars supported on bottom flanges of floor beams, and bottom of slab 1 inch below bottoms of beams. A light cinder fill is recommended, put in to the tops of the floor beams.

Fig. 359 shows long span system A, suitable for 3½-inch, 4¼-inch and 5-inch bar floors. Stirrups are placed over the upper girder flanges, and tops of slabs are flush with tops of girders.

There is also another long span system, called System B, suitable for same size bar floors as in system A. Connections to girders are made with angles bolted to bars and girders. Tops of concrete slabs are flush with tops of floor girders.

Fig. 360 shows a perspective view of the long span system B construction, with girder connections, girder covering, and brick wall connections for end spans.

Fig. 361 shows section of two-ribbed bar with angle and bolt connections for girders.

Fig. 362 shows long span system C, suitable also for the same size bar floor as in systems A and B. The bars are supported on upper girder flanges, and bottoms of concrete slabs are ¾ of an inch or 1 inch below the tops of girder top flanges.

446. THE ROEBLING FLAT CONCRETE FLOOR CONSTRUCTION, REINFORCED.—Figs. 363 to 366 show the details of this system of flat concrete construction, which is intended to meet the requirements of a light and economical floor.

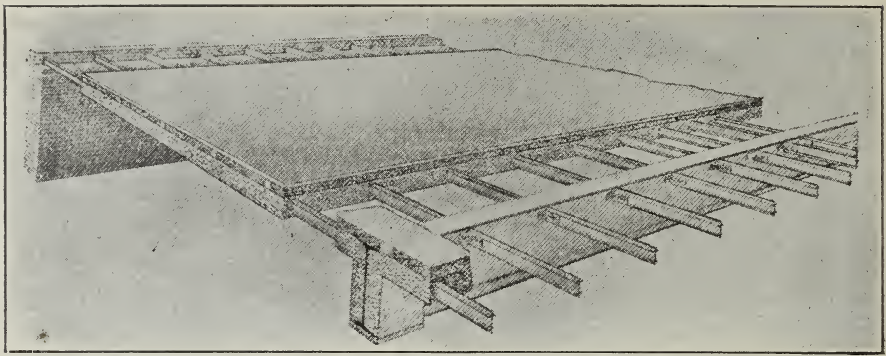


Fig. 360. Columbian System. Long Span. System B.

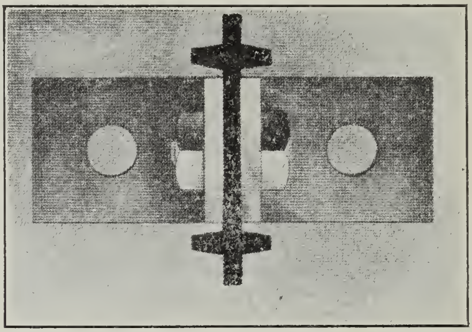


Fig. 361. Columbian System. Angle-bolt Connection.

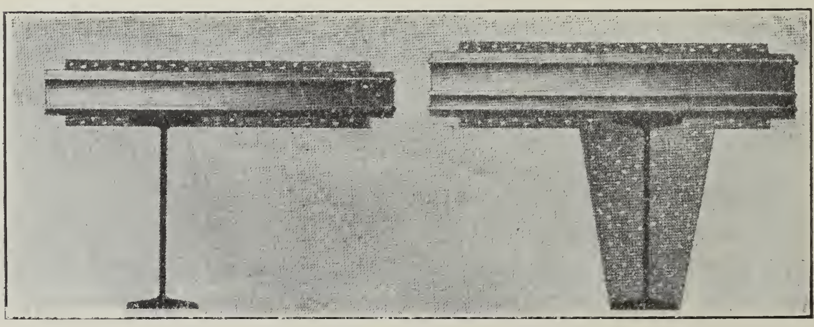


Fig. 362. Columbian System. Long Span. System C.

Fig. 363 shows a general perspective view of Type 1 of this system, with girder, beams, column, flooring and ceiling. The flat construction is known as System B, and the arched construction as System A. Type 1 consists of a light steel framework imbedded in concrete. Flat steel bars, about 2 inches wide and from ⅛ to ¼ of an inch thick, are set on edge and spaced 16 inches on centers, with a quarter turn at each end where they rest upon the floor beams. At suitable intervals ½ by ⅛-inch half-oval steel "spacers" are placed to separate and brace the bars. Temporary wood centering is erected under the latter, on which cinder concrete, made of Portland cement, sharp sand and clean steam cinder, is deposited to a thickness of at least 4 inches. A thorough protection of concrete filling is placed around both sides of the webs of floor beams

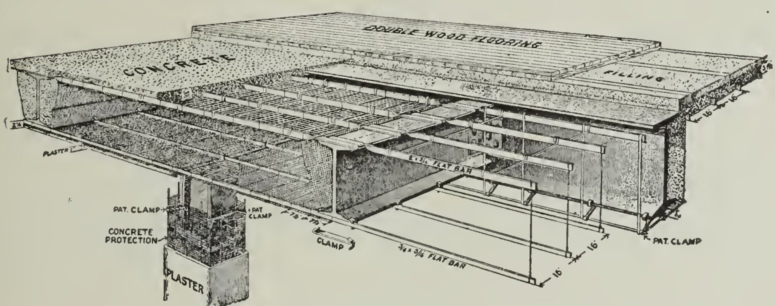


Fig. 363. Roebling Flat Construction. Type 1.

projecting above or below the surfaces of the concrete, and sloped from the edges of the flanges. A flat wire ceiling, similar to that used with the arched construction, is then put on the under side of the floor beams.

Stiffened wire lath attached to the under side of the reinforcing bars, and employed also as a centering for the concrete, may be used, and is occasionally found to be cheaper than wood centering. It also allows the moisture to drip away, often preventing injury from freezing in cold weather.

Fig. 364 shows sections of Type 1 with a plan of the floor beams, flat bars and spacers. Type 1 is used in public buildings, offices, theatres, churches, schools, hotels, residences, etc. Type 1 may be used without the hung ceiling and finished with panelling. Another type also, known as Type 2, is used. It finishes with a panelled ceiling and is adapted to stores, warehouses, depots, factories, etc.

A flat ceiling may be used with this Type 2 if desired, and in this case it is known as Type 3.

Fig. 365 shows a section of Type 4, with plan of 6-inch I-beams, placed 4 feet on centers, with flat bars placed on the lower flanges of the beams, and with a cinder fill on top of the concrete slab to the desired level. When wood centering is employed it is placed as shown by the dotted lines. Sometimes the floor nailing-strips have no filling in between, as shown on left of section. Type 4 is used for apartment-houses, hotels, etc., and other buildings in which a light floor construction is desired. Spans for this type are also made 5½ and 6 feet, with slight variations in the details, but it is not desirable when the I-beams are more than 7 inches deep.

Fig. 366 shows a section of Type 5, in which the bars are bent down 2 inches or more at the middle of the span. It is adapted to buildings the floors of which have light weights to support and in which the fire risk is not very great. It may be used for spanning the intervals between girders, omitting the intermediate floor beams. By making the spans shorter and the construction heavier, the same system can be adapted to stores and warehouses.

It has been installed successfully in spans up to 22 feet, but under ordinary conditions, considering both the fire-proofing and the steel work, the most economical results are obtained when the girders are spaced from 14 to 16 feet on centers.

The following are the weights, spacing of beams, etc., for the Roebling Flat Floor System.

Type of construction	Spacing of beams	Depth of beams	Thickness of concrete	Wt. per sq. ft. of concrete imbedded iron and wire	Wt. of ceiling, including plaster	No. of coats of plaster required
Type 1	8 ft.	10 in.	4 inches	30 lbs.	10 lbs.	3
" 2	5 ft.	10 in.	4 "	35 "	9 "	2
" 3	7 ft.	15 in.	4 "	38 "	10 "	3
" 4	6 ft.	8 in.	4 "	28 "	7 "	2
" 5	up to 16 ft.	15 to 20 in.	5½ "	45 "	7 "	2

In regard to strength, the manufacturers claim that Type 1 will carry safely, with a factor of safety of 4, and span of 8 feet, 200 pounds per square foot; and that Type 5 will carry safely, with a span of 16 feet, 100 pounds per square foot.

447. THE BERGER MULTIPLEX STEEL PLATE FLAT CONCRETE FLOOR CONSTRUCTION.—Figs. 367, 368, 369

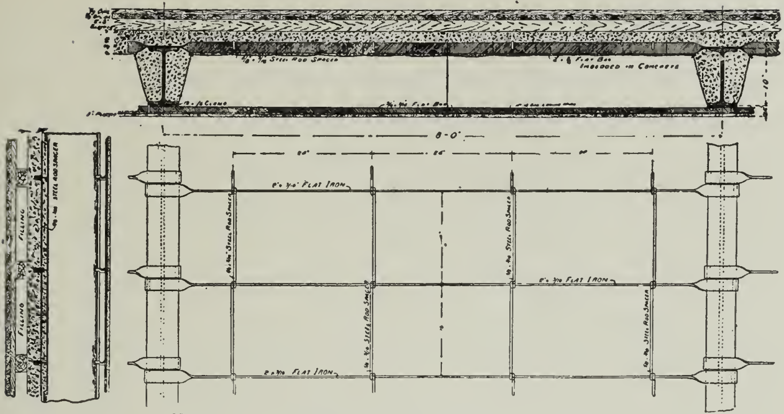


Fig. 364. Roebling Flat Construction. Type 1.
Sections and Plan.

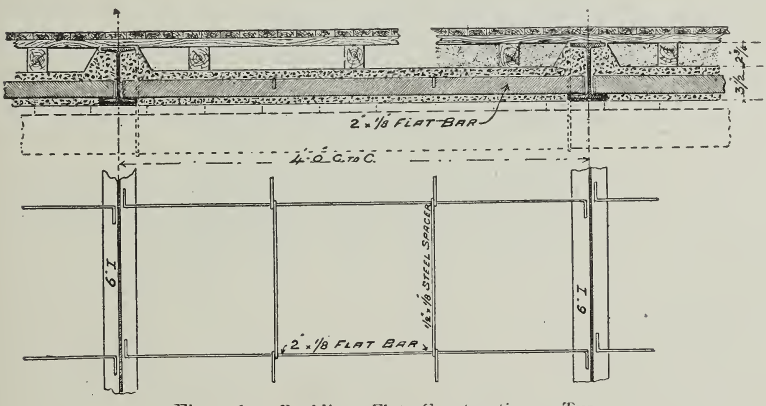


Fig. 365. Roebling Flat Construction. Type 4.
Section and Plan.

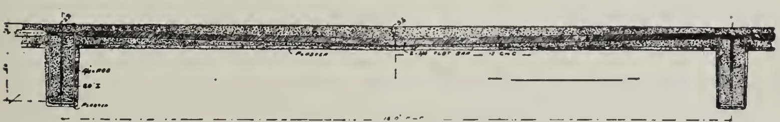


Fig. 366. Roebling Flat Construction. Type 5.

and 370 explain this flat concrete floor construction, which employs a corrugated steel plate, made by the Berger Manufacturing Company, of Canton, Ohio, and invented by Mr. G. Fugman. The plates are made of different gauges of steel from No. 16 to No. 24, No. 18 being as heavy as would be generally required, and they may be either black, painted or galvanized. They consist of a series of vertical corrugations forming three half-circle arches at top and bottom, which separate the vertical sides of the corrugations and add stiffness to the upper and lower parts of the plates.

The total depths of the plates, over all, vary for different strengths required, and are 2, 2½, 3, 3½ and 4 inches; while the horizontal widths or spaces between the manifolds or vertical sides of the corrugations remain constant at 2 inches. The lengths of the sheets vary up to and including 10 feet.

The plates are usually laid on top of the floor beams, but may be placed on their lower flanges. Concrete is filled in on top and into the corrugations, and levelled off to a depth of 1 inch above the plate for the 2-inch plates, 2 inches for the 2½-inch plates, 3 inches for the 3 and 3½-inch plates and 4 inches for the 4-inch plates, when the plates are laid on top of the beams.

In case the plates are laid on the lower flanges of beams, the concrete is filled in to the tops of the beams or higher.

When there are wood floors, the flooring strips for nailing are imbedded in the concrete and the lower surface of the strips are kept above the plates at a distance of about ½ an inch.

Among the advantages of this floor may be mentioned its strength and lightness and the omission of centering and tie-rods; and among its disadvantages, the necessity of an independently constructed ceiling, if plastering underneath is required, and the exposure of the metal ceiling to heat or fire.

In regard to its weight, strength, etc., the manufacturers give detailed data for varying spans and conditions of loading; but for purposes of comparison it may be stated that for No. 18 gauge, 4-inch plates, filled with rock concrete to a height of 1 inch above plate tops, the weight is about 39 pounds per square foot; and for an 8-feet span, a safe load of 430 pounds per square foot is given.

Fig. 367 shows one section of a Berger multiplex corrugated steel plate.

Fig. 368 shows the dimensions of these plates as ordinarily used for floor arches.

Fig. 369 shows a perspective of the Berger floor construction, with the corrugated plates resting on top of the upper flanges of the floor I-beams, and of the concrete filling, nailing strips, steel furring strips and metal lath for a flat ceiling.

Fig. 370 shows a perspective of the floor construction, with plates resting on the lower flanges of the floor beams, with concrete brought up flush with top surfaces of floor beam upper flanges.

448. THE FERROINCLAVE FLAT CONCRETE FLOOR CONSTRUCTION.—Figs. 371 to 374 show the construction of this system of floors.

There are other forms and patents of different variations of

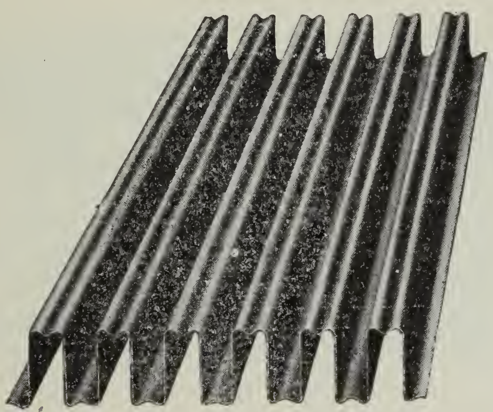


Fig. 367. Berger Corrugated Steel Plate.

corrugated or dovetailed section steel sheets. The one described under this heading is known as "Ferroinclave," and is used principally in the construction of fire-resisting flooring, roofing, siding, etc., for factory buildings, power-plants and the like. After it is secured in place it is always coated on both sides with Portland cement mortar or concrete, and becomes a reinforced concrete construction. As an article of manufacture, as well as a method of manufacture, it is patented in the United States and foreign countries, and is the invention of Mr. Alexander E. Brown, of the Brown Hoisting Machinery Company of Cleveland, O.

Ferroinclave is generally made of No. 24 U. S. gauge box

annealed sheet-steel, each sheet being accurately crimped into the dovetailed section shown. The corrugations are ½ an inch in depth, 2 inches center to center, with an opening between the edges of ⅞

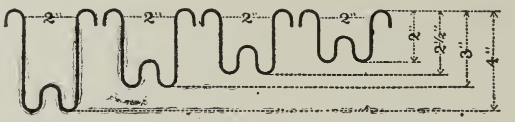


Fig. 368. Berger Corrugated Steel Plate. Dimensions.

of an inch. They are made wider at one end of each sheet than at the other, so that sheets may, if desired, shingle or fit endwise into each other; or they may be had with non-tapering corrugations.

Full-sized sheets are 20⅝ inches wide by 10 feet long; and the

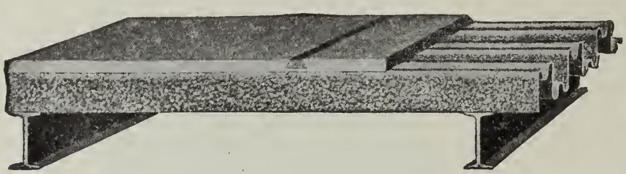


Fig. 369. Berger Floor System. Plate on Beams.

covering width of each sheet, that is, the distance from center to center of side laps, is 20 inches.

Among the advantages of this type of corrugated sheets for floor construction may be mentioned the small size of the corrugations allowing plastering on the under side; and a strength sufficient, with moderate spans, to hold the concrete without wood centering, thus saving the cost of same, and the time used in erecting it and taking it away.

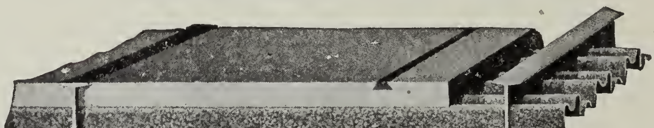


Fig. 370. Berger Floor System. Plate on Lower Flange.

Among the disadvantages may be mentioned the increased cost of the sheets on account of transportation charges, when shipped any distance, making it difficult to compete, under such conditions,

as far as cost alone is concerned, with many reinforced concrete systems.

The concrete mixture used for floors in this system is usually a rich gravel or crushed stone concrete of a thickness determined by the loads and span.

In regard to strength, tests have been made on No. 24 ferroinclave and the ultimate strength determined for different thicknesses of concrete, the span being 4 feet 10½ inches, and the sheets being 20 inches wide. The results of the tests have been tabulated as follows:

Thickness of 1 to 2 mortar above the metal	1½″	2″	2½″	3″	3½″	4″
Ultimate strength in pounds per square foot (span 4 ft. 10½ ins.)	615	915	1220	1560	1860	2120

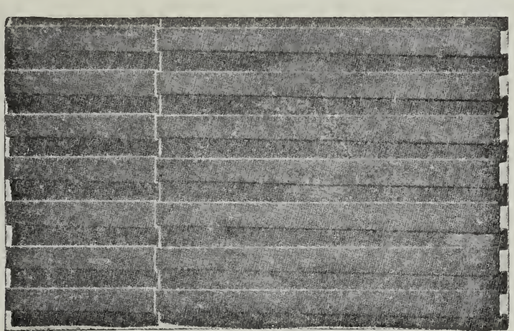


Fig. 371. Ferroinclave Sheet.

To get the safe load, a factor of 6 is generally used for ordinary loading.

In addition to the uses mentioned already, ferroinclave is employed in the construction of partitions, stair treads and risers, gutters, vats, tanks, bins, fire-proof doors, cornices, moldings, bridge floors, etc.

Fig. 371 shows a sheet of ferroinclave.

Fig. 372 shows a partial section of the sheets lapped, with cement concrete above and plaster below the sheets.

Fig. 373 shows section and perspective of construction used for segmental floor arch.

Fig. 374 shows perspective of flat floor construction, looking down.

448a. THE WHITE CONCRETE FLOOR CONSTRUCTION.—Figs. 371, *a, b, c, d* and *e*, show this construction, patented and controlled by the White Fire-proof Construction Company, New York, and introduced into use some years ago. This system has been used in important buildings and is well spoken of, the round reinforcing rods being correctly located in the concrete for maximum tensile strength and general efficiency. The claims are made that the monolithic character of the concrete is not in any way destroyed by the presence of the rods, as they occupy a minimum of space, and that on account of the simplicity of the construction it can be installed very rapidly.

Figs. 371, *a* and *b*, show systems *A* and *B*, which are types of flat arches, with and without metal lath and plaster ceilings. There is a wide range of modifications, such, for example, as the raising or lowering of the slab to accommodate plumbing pipes, electrical conduits, etc. In cases where the steel beams are spaced not more than 7 feet apart cinder concrete is used. This form of construction has been subjected to the severest fire, water and weight tests, 2,350 pounds having been placed upon each square foot of surface of a floor arch of this kind without causing any sign of failure whatever; and it lends itself particularly well for use in office-buildings, lofts, factories, hotels and dwellings.

Fig. 371, *c*, shows System D, an adaptation for long spans, in which stone replaces cinders in the mixture, and the reinforcing rods are spaced according to the loads to be carried.

Fig. 371, *d*, shows System E, a variation in which the concrete slab is approximately flush with the under side of the floor beams. This makes a flat surface ready for plastering without any further preliminary work. In using this form of construction it is necessary to have the under side of the steel beams in the same horizontal plane, and, as the space from the top of the arch to the top of the beams is filled in with concrete cinder fill, it is desirable to use only the smaller sizes of beams in order to avoid excessive dead loads. This system is particularly adapted for use in apartment-houses, etc.

Fig. 371, *e*, shows System F, which includes several forms of segmental arches, with tension members imbedded. This form of construction is capable of carrying very large live loads, and is largely used in breweries, power-houses, etc. See arched forms of concrete floor construction, Articles 442 and 443.

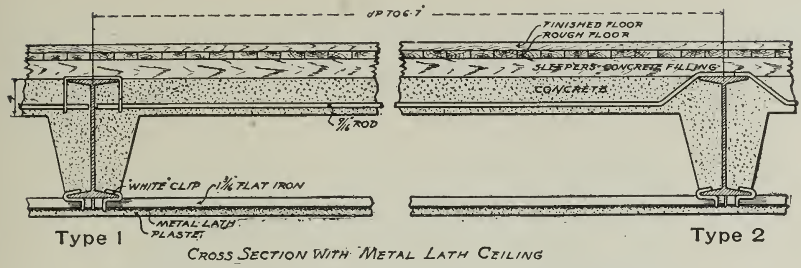


Fig. 371-a. White Concrete Flat Floor Arch, System A.

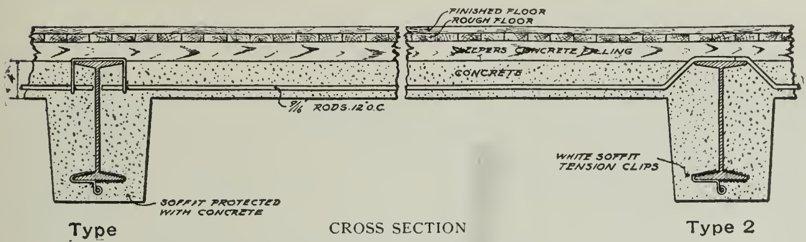


Fig. 371-b. White Concrete Flat Floor Arch, System B.

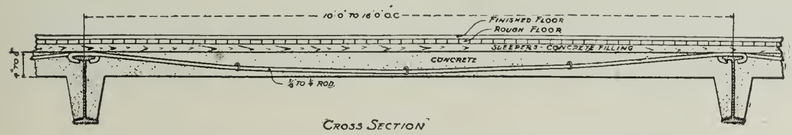


Fig. 371-c. White Concrete Long Span Flat Floor Arch, System D.

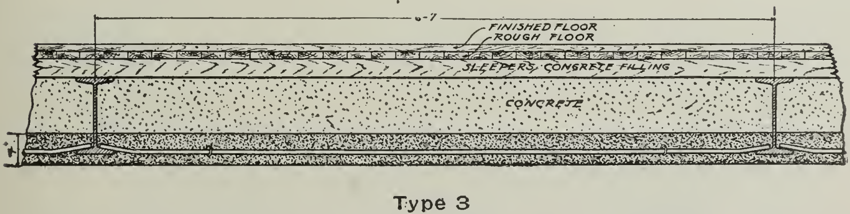


Fig. 371-d. White Concrete Flat Ceiling Floor Arch, System E.

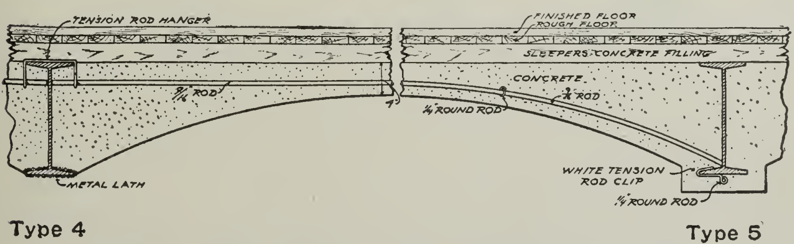


Fig. 371-e. White Concrete Segmental Floor Arch, System F.

449. UNPATENTED SYSTEMS OF FLAT CONCRETE FLOOR CONSTRUCTION, REINFORCED.—Some of the patented systems of flat concrete floor construction having been con-

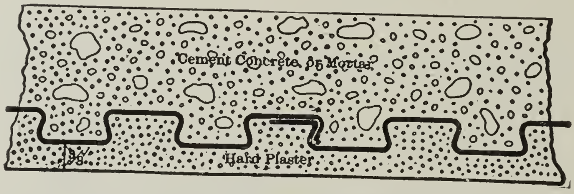


Fig. 372. Section Through Ferroinclave Floor.

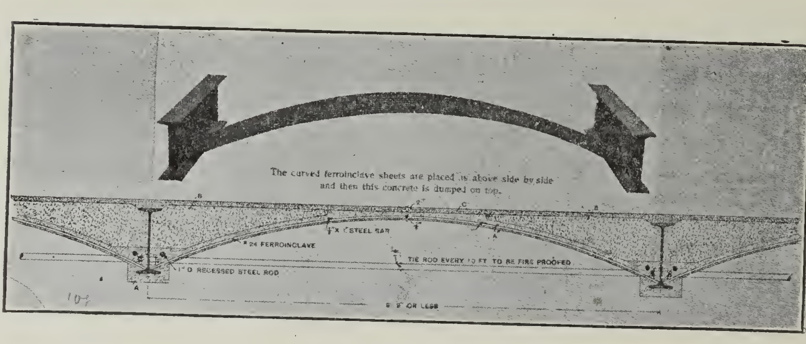


Fig. 373. Ferroinclave Floor Arch System.

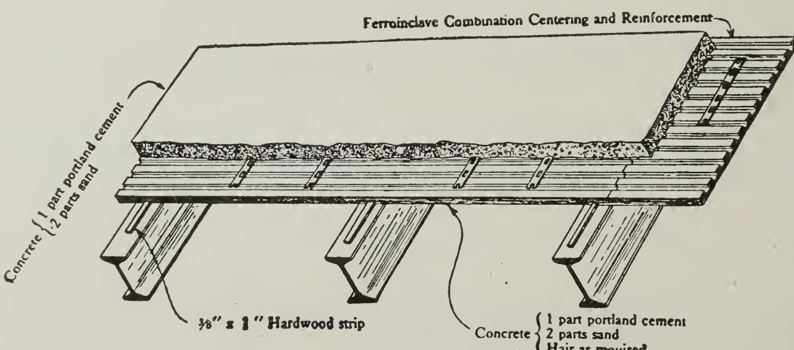


Fig. 374. Ferroinclave Flat Floor System.

sidered, some of the unpatented systems will now be briefly referred to.

450. EXPANDED-METAL FLOOR REINFORCEMENT.—Fig. 375 shows the diamond mesh expanded-metal used in concrete

fire-proof floor construction. Fig. 376 shows a section of one kind of expanded-metal reinforced floor with steel I-beam construction, and Fig. 377 shows a section of floor with reinforced concrete beams.

The advantages claimed for this material for floor reinforcement

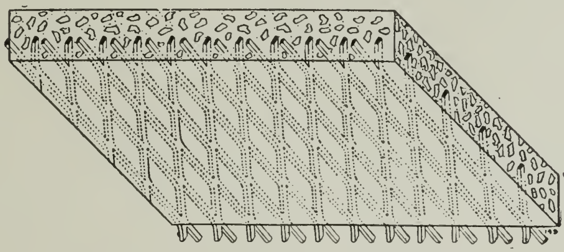


Fig. 375. Expanded-metal. Diamond Mesh.

may be enumerated as follows: (1) a superior mechanical bond with the surrounding concrete; (2) a more advantageous arrangement of the material in the concrete than with an equal amount in any other form; (3) a method of manufacture which results in an

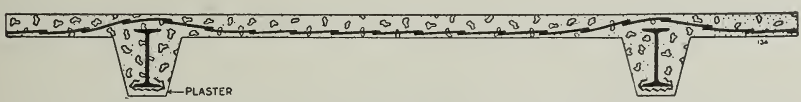


Fig. 376. Expanded-metal I-beam Floor Construction.

increased ultimate strength and high elastic limit, resulting in (4) the combined advantages of a high ultimate strength with a low-carbon steel; (5) a uniform distribution of small sections at frequent intervals; and (6) great efficiency in resisting stresses devel-

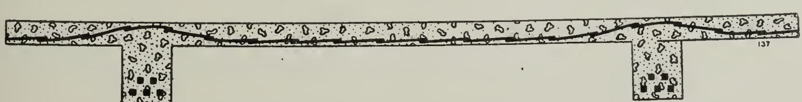


Fig. 377. Expanded-metal Reinforced Beam Construction.

oped by concentrated loads, due to the oblique direction of the divisions of the mesh.

Expanded metal is manufactured from soft, tough steel, fine in texture, and of a thickness which varies from No. 16 to No. 4, Stubbs' gauge. The length of the sheets of metal is 8 or 12 feet, and the width varies, according to the width of the mesh, from 3

to 6 feet. In floor construction the 3-inch mesh is generally used, the width of the diamond-shaped openings determining the designation of the mesh.

451. LOCK-WOVEN FABRIC FLOOR REINFORCEMENT.—Figs. 378 to 381 show the character, form and use of the lock-woven steel fabric employed in fire-proof concrete floor construction, and manufactured and sold by W. N. Wight & Company, New York. There are a great many forms of floor arches that can be constructed with the use of this reinforcement, most of them being patented; but any one using it may adopt any form desired. One of the advantages of this fabric is the stretching or extending from wall to wall, making a continuous tie. It can be obtained either "bright" or galvanized, the latter costing 1⅓ cents more per square yard than the former; and it can be woven of any gauge wire and with any size mesh, oblong or square.

The width of the "standard" fabric is 56 inches, but it can be increased up to 88 inches; and it is put up in rolls of from 330 to 500 lineal feet; or less, if required.

High carbon steel wires crossing each other at right-angles, as shown in Fig. 378, are used in the weaving, the longitudinal strands in the standard fabric being of No. 10 wire, B. & S. gauge, placed 4 inches on centers, and the cross strands being of No. 9 wire, placed 6 inches on centers. The crossing strands are locked at the intersections with No. 9 wire twisted around as shown in the detail in Fig. 378. The weight of the standard fabric is two-tenths of a pound per square foot.

Figs. 379, 380 and 381 show three of many systems, with spans, loads and tests indicated, Fig. 379 showing a panelled ceiling, Fig. 380 a flat ceiling and Fig. 381 a special design for light floors on wide spans.

The catalogues of the manufacturers give detailed data regarding the strength of the various systems, and the approved tests.

452. STEEL-WIRE FLOOR REINFORCEMENT.—Figs. 382 and 383 show the general form of the steel wire fabric used for the reinforcement of fire-proof floors, and manufactured by the American Steel and Wire Company, of Chicago, Fig. 382 showing the "triangular mesh" and Fig. 383 showing the "square or rectangular mesh."

The triangular mesh steel wire reinforcement is particularly

adapted to floor-slabs, curtain and retaining-walls, bridge spans and reservoirs; and the square mesh steel wire reinforcement is particularly adapted to concrete columns, water mains and sewers.

The longitudinal or tension members of the triangular mesh reinforcement are made either stranded or solid, and the triangular form of mesh is manufactured in rolls of approximately 150-, 300- and 600-feet lengths, and in standard widths of from 18 to 58 inches. The distance on centers of the longitudinal or tension members is usually 4 inches, and the distance on centers of the diagonal, bond or cross-members either 2 or 4 inches as desired.

The above data apply also to the square or rectangular mesh steel wire reinforcement, except that the cross or bond wires are spaced 4, 6 or 12 inches apart.

This steel wire reinforcement is not as a rule galvanized, as there is a stronger bond between the steel and the concrete when the galvanizing is omitted. The manufacturers will furnish the wire galvanized, however, if so desired.

They offer 88 stock styles of the triangular mesh and 28 styles of the square; and furnish detailed data regarding strength, tables, formulas, illustrations of application, weights per square foot, cross-sectional areas of wires, total cross-sectional area of reinforcement, etc.

453. WELDED METAL FABRIC OR MESH FLOOR REINFORCEMENT.—Fig. 384 shows the general form of this kind of reinforcement, and Fig. 385 shows in detail a piece of the electrically welded fabric so cut as to expose the weld between the longitudinal and transverse wires. It is claimed by the manufacturers that it is not possible to detect the point of junction between the two wires on account of the perfect weld. This fabric is made by the Clinton Wire Cloth Company, of Clinton, Mass.; and the principal advantages claimed for it for floor slab construction are the adaptability to variations in size and spacing of wires to give the necessary area for any given weight and span; the coincidence of the direction of the wires with the line of stress, thus diminishing the tendency to any distortion of the rectangles of the mesh; and the rigid holding in place of the carrying wires by the cross wires welded to them, and the consequent prevention of the slipping of the former in the concrete.

This form of reinforcement has been extensively employed for

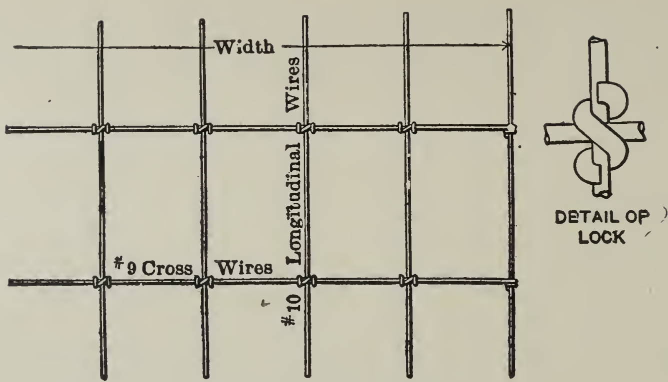


Fig. 378. Lock-woven Fabric.

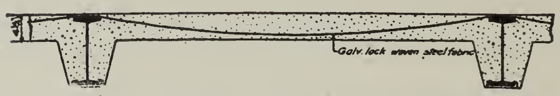


Fig. 379. Lock-woven Fabric Floor Construction.

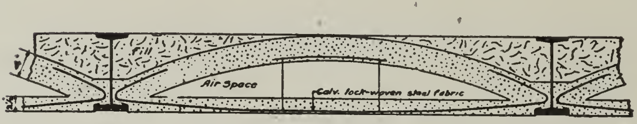


Fig. 380. Lock-woven Fabric Floor Construction.

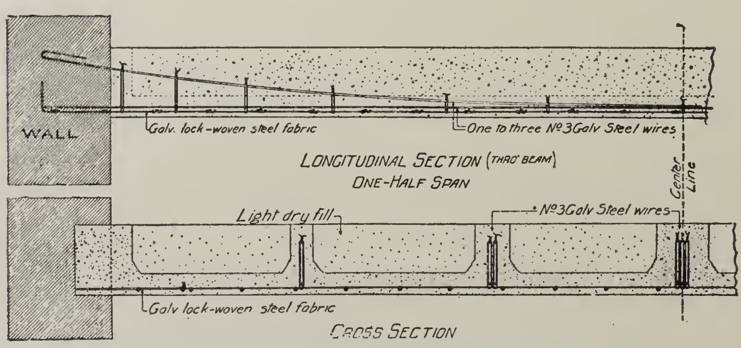


Fig. 381. Lock-woven Fabric Floor Construction. Wide Span.

all kinds of concrete construction, The sizes of meshes and wires vary through a wide range, usual meshes being from 1 to 4 inches on centers, with from No. 10 to No. 3, Washburn and Moen gauge,

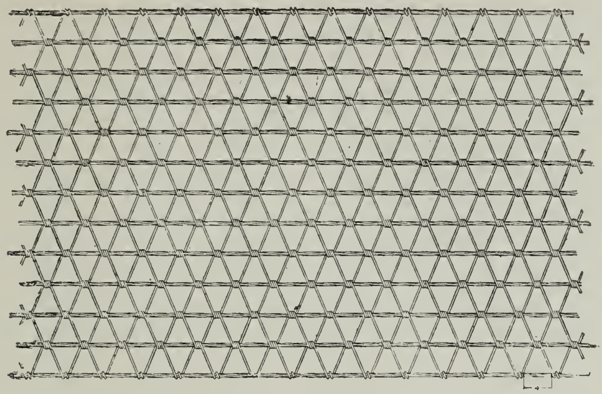


Fig. 382. Steel Wire Reinforcement. Triangular Mesh.

for the carrying wires, and from No. 11 to No. 6, placed from 3 to 12 inches on centers for the distributing wires.

The material is sold in long rolls varying in width from 48 to 86 inches, and when it is laid over the tops of the floor beams laps

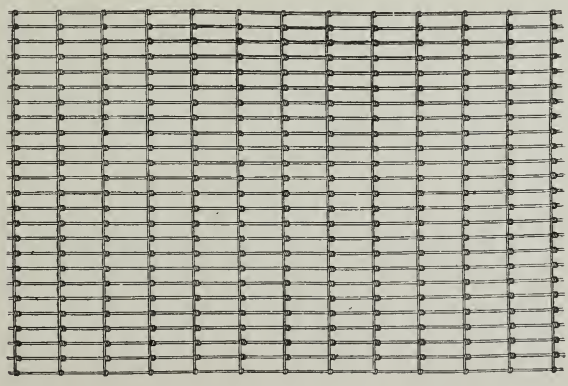


Fig. 383. Steel Wire Reinforcement. Square Mesh.

and joints are avoided, and a continuous metal bond extends from wall to wall.

Tests for strength have given exceedingly satisfactory results,

and especially so when compared with the lightness of the material.

454. THE MERRICK SYSTEM OF CONCRETE FLOOR ARCH CONSTRUCTION.—Figs. 386 and 387 show the general construction of this reinforced flat concrete floor system, which is controlled by Mr. Ernest Merrick, New York.

The figure shows what is known as construction "A," the form used for ordinary spans. In the long-span construction "B," two 13/16-inch reinforcing rods are used in the concrete ribs between the metal fabric forms, one of the rods running horizontally in the lower part of each concrete rib and the other rod running horizontally and next to and parallel to the first, through about one-third of the span, and then curving up to the upper part of the concrete ribs and running horizontally into the concrete part of the floor system over the walls or bearings, following thus, approximately the "bending moment curve." This latter form has been employed in spans of 16 and 18 feet, the floor being built from girder to girder, doing away with all steel I-beams, and proving satisfactory and economical.

This type of flooring consists of a series of reinforced concrete beams connected as shown by a concrete plate at the top and a concrete ceiling plate at the bottom, the width of the span and the amount of the load determining the size of the concrete beams and the percentage of reinforcement.

The lower or ceiling slab is always made of cinder concrete, as it is a better fire-resisting material than stone concrete; and in the long-span construction the upper concrete slab part is made of stone concrete for greater strength.

A flat wooden centering is put up first, and on it is placed a 2-inch thickness of cinder concrete. Before the latter has fully set, wire lath or sheet metal cores or cages, without bottoms, and made of very inexpensive material, are put in position on it, the lower edges thus becoming imbedded. These fabric cores are left in place, the reinforcing rods set and the concrete filled in between and above the fabric.

The disadvantages are the necessity of a uniform spacing of the floor beams; greater cost of factory forms than of centering in place at the building; the use of a richer and more carefully prepared concrete mixture, necessitated by the extra strength required

in pieces to be handled; and the loss by breakages during transportation.

c. 3. SECTIONAL CONCRETE FLOOR CONSTRUCTION.

455. GENERAL DESCRIPTION.—This is the third division of the concrete fire-proof floor construction. The general principle

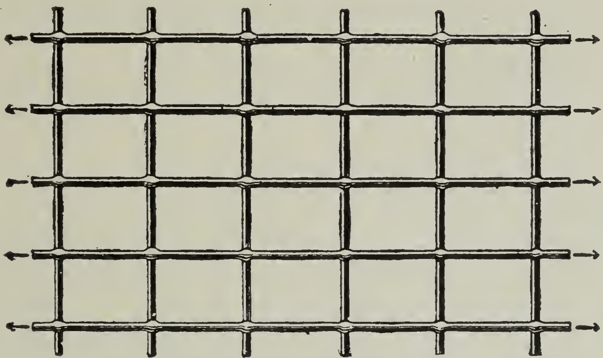


Fig. 384. Welded-metal Fabric.

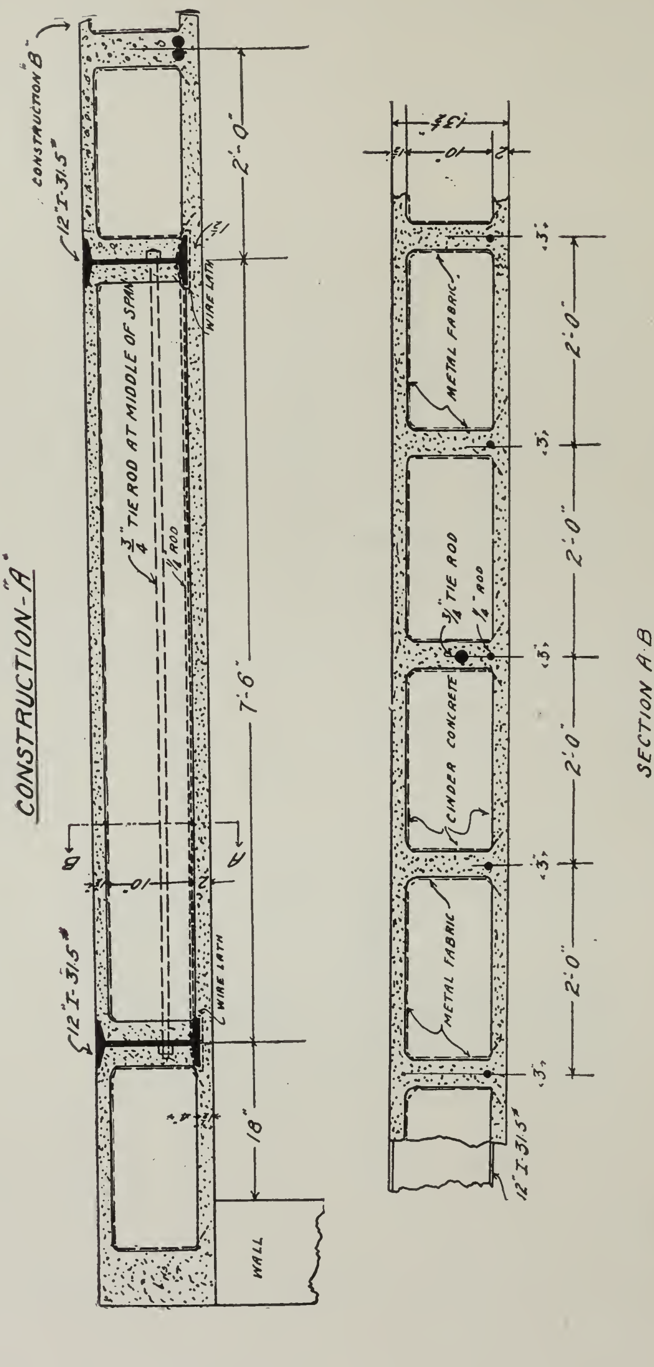
of this type of fire-proof floor construction is a factory-made unit, completely finished and then taken to the building and set in place between the steel floor beams.

The advantages of this system are the saving of the labor and expense of centering, little or no centering being used; the greater assurance of a uniform and perfect mixture of concrete materials

Fig. 385. Welded-metal Fabric. Detail.

by more skilled labor at the factory; and a consequent additional saving of time.

456. THE "HOLLOW CONCRETE I-ARCH" FLOOR CONSTRUCTION.—Fig. 388 shows one type of sectional con-



Figs. 386 and 387. Merrick System of Floor Construction.

crete floor construction, commonly called the "Hollow Concrete I-arch," or the "End-construction Concrete Tile," and made and used by the Standard Concrete Steel Company of New York. The figure shows also two types of beam covering and flange protection. The concrete I-beams, which are made at the factory and thoroughly hardened before being sent to the building, are 10 or 12 inches deep, and have their lower flanges reinforced with either steel rods or channels, around which the concrete is compacted by special machinery. The steel I-beams are spaced from 5 to 7 feet apart, and on their lower flanges rest the concrete I-beams, the

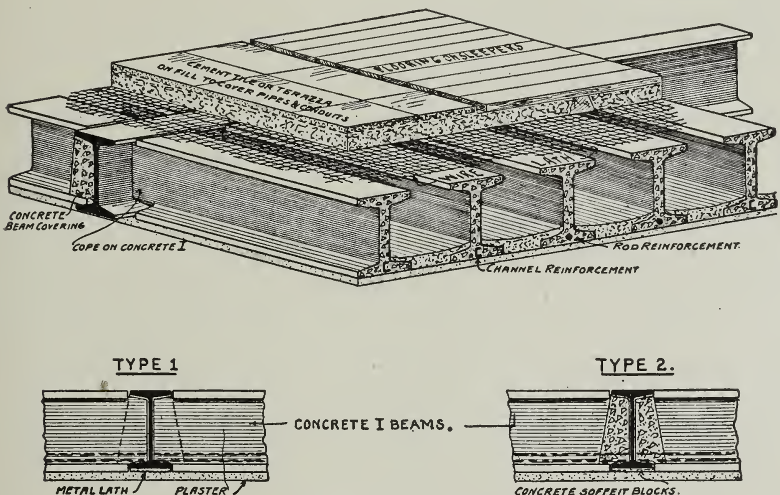


Fig. 388. Hollow Concrete I-arch Floor.

latter being set about 12 inches apart, and having their lower flanges and the spaces between them filled in with a cinder concrete of a similar mixture to that of the concrete I's themselves.

The ceiling is level, and the webs of the steel I-beams are protected, as shown, between the concrete I's by concrete, which is used also to fill in at the ends of the concrete I's, where inequalities in lengths occur. Some small-mesh metal fabric is placed over the tops of the concrete I's, and on this the concrete slabs, cement tiles, terrazzo on concrete fill, or wood flooring on sleepers, as desired.

457. THE THATCHER FLOOR UNIT SYSTEM.—One

type which may be mentioned as giving a very light, strong and economical floor is the sectional floor system made by the Concrete Steel Engineering Company, of New York, and called the "Thatcher Floor Unit." These units of concrete are made for any required load or span; cast in suitable molds, usually about 2 feet in width, or in any width convenient for hauling; allowed to harden or set at the factory for a month or two, and then brought to the building, set in place and dovetailed together with cement mortar.

458. OTHER SYSTEMS OF SECTIONAL CONCRETE FLOOR CONSTRUCTION.—There are several types of sectional concrete floor construction, some of which have not been very successful commercially, and are no longer on the market.

3. BEAM AND GIRDER PROTECTION.

459. GENERAL CONSIDERATIONS.—The metal to be covered and protected may be either a simple steel floor beam or a girder; and the girder may be a single, double or triple I-beam girder, a plate-girder or a box-girder. The principal materials used for covering and protecting are either terra-cotta or concrete. The terra-cotta may be dense, semi-porous or porous, and the concrete may be made of stone, cinders or slag. The terra-cotta incasing blocks may belong to either one of two types of construction; to the one in which the blocks incasing the lower flanges of the steel beams meet below and at the middle of the flange, or to the one in which the blocks cover the edges only of the lower flanges, and hold up with their bevelled edges pieces of flat tile against the under side of the steel beams. The beams or girders may or may not project below the floor construction.

Plaster composition material is not recommended for beam and girder protection, and the use of hung ceilings for the purpose only of such protection is not considered good practice. Recent large conflagrations have shown that such ceilings are apt to come off and expose the beams or girders.

It is customary to employ the same material for the covering of the beams and girders that is used for the construction of the floor arches or slabs themselves.

All the metal used in the construction and support of fire-proof floors, including all parts of steel beams and girders, should be thoroughly and permanently covered and protected; and while there

are most excellent systems of terra-cotta fire-protection, aside from any questions of fire-resisting properties of the materials themselves, it is generally admitted that a more thorough incasing of the webs and lower flanges of beams and girders can be effected by the use of concrete. The superior fire-resisting properties of cinder concrete are well known, and when the incasing portion has sufficient thickness, 2 inches or more, and is put in place with sufficient care, it will remain securely in position without the aid of reinforcement. When less than 2 inches thick, metal fabric, imbedded, is put around the flanges.

Some of the types of floor construction are those in which such construction itself incases the sides of the I-beams, and in which the ceilings are not panelled; while there are other types in which part of the floor I-beams project below the floor construction, and in which the ceilings are panelled. These different types are indicated in the preceding figures of floor arches. In the former case the beam incasing should have a minimum thickness of 1 inch and in the latter case it should have a minimum thickness of 1½ inches.

460. TERRA-COTTA BEAM AND GIRDER PROTECTION.—*A. Beam Protection.*—The first type is the one in which the incasing tile blocks meet under the lower flanges of the steel I-beam. Figs. 312, 313, 314, 315, 316, 322, 328, 330, 331, 332, etc., show various forms and variations of this type. These incasing blocks may be either the floor arch skew-backs or separate blocks. The entire I-beam may be covered by the terra-cotta blocks, as in those systems in which the floor tiles run over the I-beams with some reinforcing material between them and the beams, like the "Johnson" arch, for example.

The second type is the one in which the incasing tile blocks cover the I-beam flange edges only, holding up by their own bevelled edges pieces of flat tile against the under side of the metal flange. Figs. 319, 324, 329, 334, etc., show various forms of this type.

B. Girder Protection.—Figs. 389 and 390 show typical methods of protecting box-girders and double I-beam girders with hollow terra-cotta blocks; and Fig. 391 shows a method for a single-beam girder which comes at the side of a hatchway or other similar opening in a floor. See also other figures.

When girders project below the ceiling line, as is usually the case, they should have ample protection because of their great

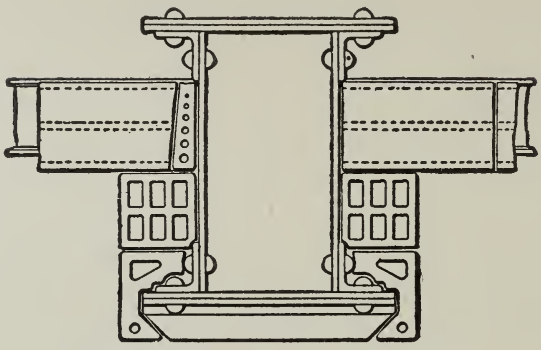


Fig. 389. Tile Protection for Box-girder.

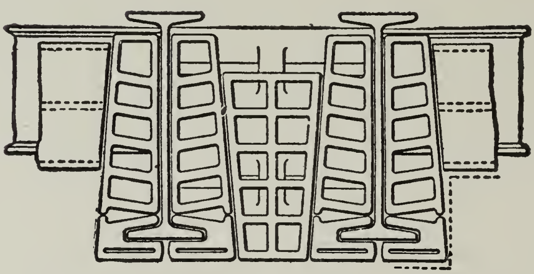


Fig. 390. Tile Protection for Double I-beam Girder.

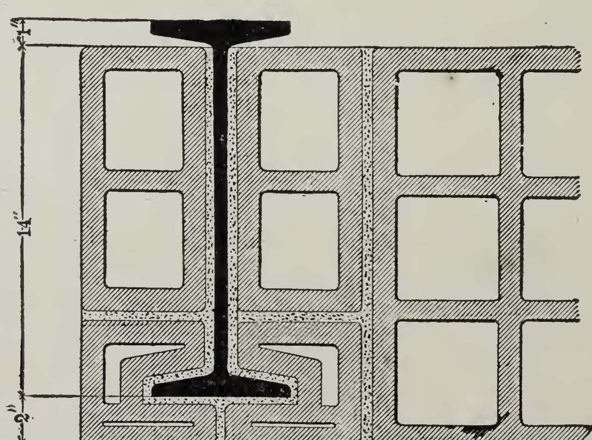


Fig. 391. Tile Protection for Single I-beam Girder.

exposure to the heat and water accompanying a serious fire in the building. For the best results the minimum thickness of the terra-cotta protection should be 4 inches on the sides and $1\frac{1}{2}$ inches under the lower flanges of the girder, and there should also be a space of about $\frac{1}{4}$ of an inch between the beam and the tiles. As an extra precaution and to prevent the side flange tiles from spreading, wire ties are inserted in the holes shown in Fig. 389, and placed in the opposite end-joints of the soffit tiles.

461. CONCRETE BEAM AND GIRDER PROTECTION. —*A. Beam Protection.*—Figs. 349, 350 and 353 show different forms and variations of this kind of beam protection, Fig. 353 showing a soffit air-space for additional security against the effects of great heat.

B. Girder Protection.—Many of the figures drawn to illustrate concrete beam protection illustrate also girder protection. The methods employing the air-space are especially recommended for girders, and have shown good results in some test cases. An illustration showing one of the typical Roebling methods of cinder concrete girder protection is given in Fig. 392.

4. FIRE-PROOF FLOORING.

462. GENERAL DESCRIPTION.—The building laws of some cities require that in all buildings a certain number of feet in height, usually 150 feet or over, the floor coverings shall be either of wood treated by some fire-proofing process, or of some incombustible material, such as cement, tile, stone, marble or approved fire-proof composition.

While in many kinds of buildings, aside from questions of fire-resistance and durability, *wood* is a more desirable material for flooring, because of its relative warmth and softness, still for many other kinds of buildings the other materials mentioned are appropriate and have been widely used.

Cement floors are used in such buildings as factories and warehouses, and in the guest-rooms of many hotels, in which last case the carpets are laid over the cement and tacked to bordering of wood strips.

Tiles of various materials are used in public rooms, halls and corridors, and *asphaltic* flooring also is often employed.

There are numerous makes of *composition* flooring on the market

which have been used in many recent buildings with more or less success. The result striven for in their manufacture is to obtain a flooring material, generally in the form of a dry powder, which, when properly mixed with specially prepared liquids and spread over a surface, will make a smooth floor without joints, of almost any color, with sufficient resistance to wear, fire-resisting, non-absorbent, elastic and of reasonable cost. An added advantage in their use is the possibility of carrying the material up the side walls, with a small cove or "sanitary base" at the floor angles, thus making one continuous jointless surface.

These composition floors are composed of different mixtures containing such materials as asbestos, magnesite, sawdust, sand, mag-

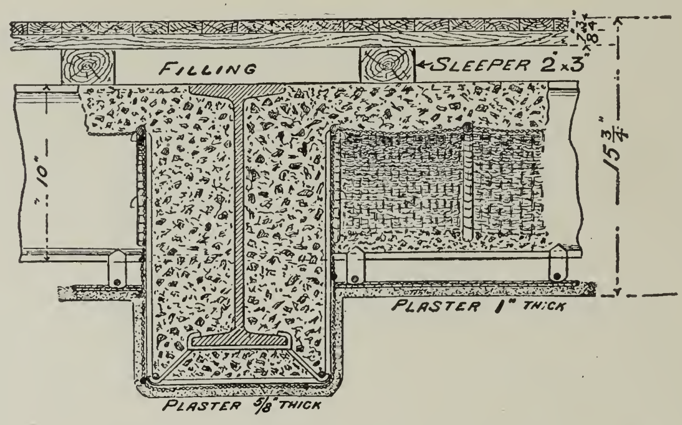


Fig. 392. Cinder Concrete Girder Protection.

nesium chloride, etc., and are sold under various names, such as, for example: "Alignum," "Asbestolith," "Asbestos Granite," "Carborundum," "Crown Sanitary Flooring," "Karbolith," "Lignolith," "Magnesia Building Lumber," "Monolith," "Puritan," "Rex," "Sanitas," etc.

5. FIRE-PROOF ROOFS AND ROOF-COVERINGS.

463. *A.* FIRE-PROOF ROOFS. GENERAL CONSIDERATIONS.—Roofs in this division of the subject may be considered under the headings of Flat Roofs and Pitched Roofs, and the latter may be again conveniently subdivided into the ordinary Pitched Roofs, Mansard Roofs and Trussed Roofs.

The details of construction of fire-proof *flat roofs* and of fire-

proof floors are practically the same, about the only difference being, in the case of roofs, lighter beams and arches or fillings, and a setting of the steel framing out of level to obtain a slight pitch.

The material for the roof arches or panels may be terra-cotta or concrete as for floors, put in place in the same way.

The question of protection against damage by fire should receive careful consideration in roof construction, and all metalwork, in the roof space, such as steel beams, channels, girders, columns, etc., should be well covered with approved protecting materials.

The details of ordinary *pitched roofs* of fire-proof construction vary with the roof-panel materials and the covering of the same. The fire-proofing material may be terra-cotta blocks with or without reinforcing, or reinforced concrete. The ordinary terra-cotta floor blocks and I-beams may be used with floor-arch construction; or terra-cotta "book-tiles" or roofing tiles may be set on and between T-iron purlins, placed horizontally on the I-beam rafters. Any system, also, of reinforced concrete or of reinforced terra-cotta tiles may be employed without purlins.

The rafters and all other metal should be amply protected with proper coverings, with terra-cotta in the case of terra-cotta roofs and with concrete and metal lath in the case of concrete roofs. When the purlin construction is used it is difficult, if not impossible, to thoroughly protect the purlins without great expense.

The details of the *mansard* type of protected fire-proof roofs differ somewhat from those of the ordinary pitched roofs. The spacing of the steel rafters, which are generally secured to metal wall-plates by bolts or rivets, depends upon the fire-proofing material used. This material may be terra-cotta in the form of hollow partition tiles, or concrete, or tile blocks in single lengths between rafters. The spacing on centers of the rafters is from 5 to 6 feet for partition tile or concrete, and the maximum spacing for single-length blocks is 2 feet.

Trussed Roofs also may be constructed with the fire-proof roof materials either extending from truss to truss and connected directly with the steel angle, channel, etc., truss rafter members; or placed between or over horizontal steel purlins of various shapes resting on the truss rafters.

But while the roof-panels and coverings may be fire-proof, the roof structure as a whole cannot be so considered unless all the

metal of the trusses is protected in some approved manner. While it is possible to cover the truss members with terra-cotta or concrete coverings, it is not always attempted, on account of the expense. In open truss roofs the trusses are commonly left unprotected, and where they are enclosed with a ceiling, that alone usually serves as the protection against fire.

Fig. 393 shows typical book-tiles for roofs. They are usually made in 3- and 4-inch thicknesses, in 12-inch widths and in 18-, 20- and 24-inch lengths. Solid porous terra-cotta blocks of about the same shapes and sizes are used in a similar manner in place of the hollow tiles, when the roof covering is of slate or clay tiles, as they hold nails better. Fig. 394 shows one type of mansard roof construction, with 5-inch I-beams and diagonal or straight setting of blocks, which are grooved for one or both flanges of the beams. Fig. 395 shows a concrete arch fire-proof roof construction and also a suspended ceiling. Fig. 396 shows pitched roof construction on trusses, with purlins spaced from 5 to 8 feet apart, expanded-metal, and slates nailed directly to cinder concrete. Fig. 397 shows pitched-roof construction on trusses, without purlins, and with application of reinforced concrete with the Kahn trussed bar in connection with hollow tile.

464. *B.* ROOF COVERINGS FOR FIRE-PROOF ROOFS.—The principal materials used for the coverings of fire-proof roofs are, for pitched roofs: 1. Tin or copper; 2. Roofing slate; 3. Clay tiles; 4. Metal tiles. For flat roofs the materials are: 1. Tar and gravel; 2. Asphalt with gravel or with sand; 3. Vitrified tiles or slate tiles or bricks over tarred felt. Tin or copper may be used on flat roofs which are not to be walked over.

When tin or copper is used, wood nailing-strips are imbedded in the concrete or the concrete filling, and a wood sheathing is laid in order to prevent the metal roof covering from being destroyed by rust.

Ordinary roofing slate is frequently used for pitched roofs. It will not stand exposure to fire to the same extent as will clay tiles of the best make and design. The slates may be nailed directly to solid porous terra-cotta blocks, or to cinder concrete, but not to dense tiling nor to rock or gravel concrete.

Regarding the nailing, the same may be said for clay tiles as for metal tiles.

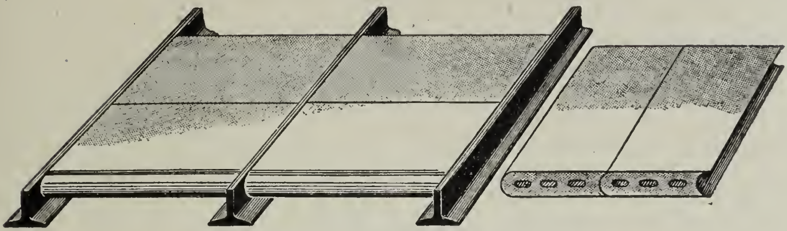


Fig. 393. Terra-cotta Book-shape Roof Tiles.

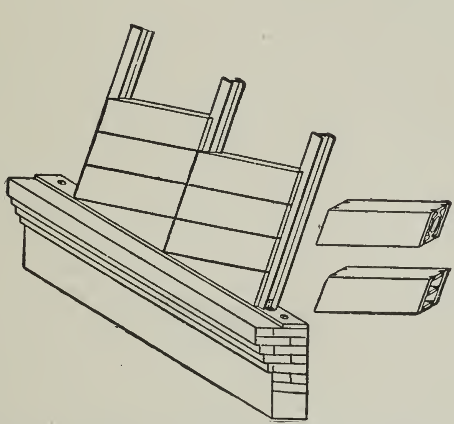


Fig. 394. Tile Construction for Mansard Roofs.

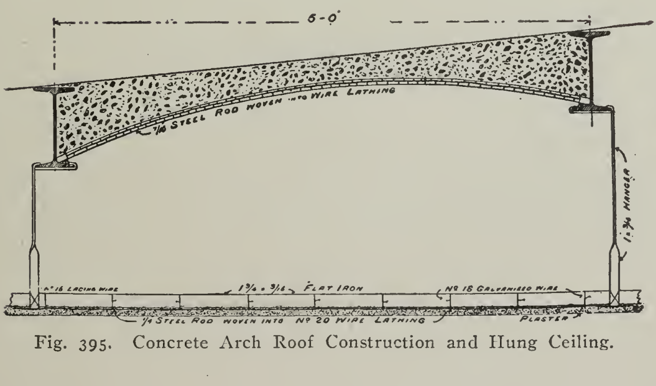


Fig. 395. Concrete Arch Roof Construction and Hung Ceiling.

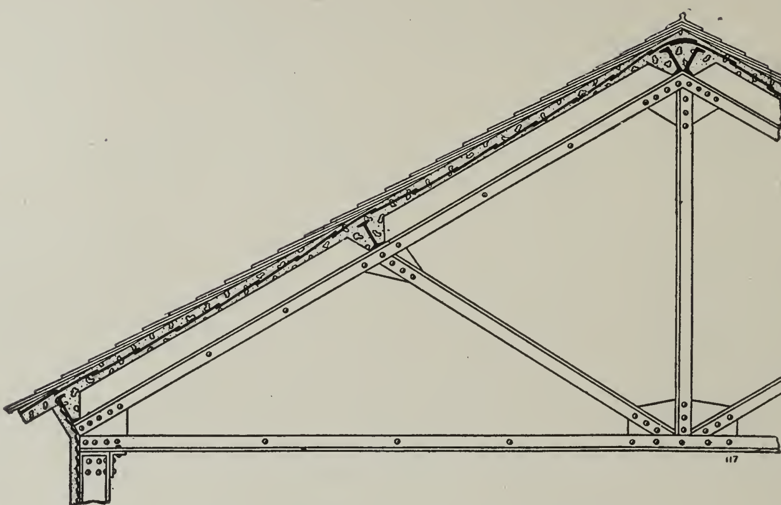


Fig. 396. Concrete Roof for Truss Construction.

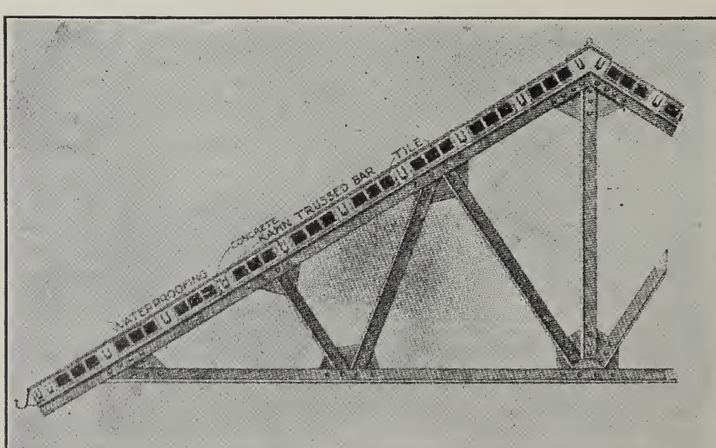


Fig. 397. Concrete and Tile Roof Construction.

Gravel roofing with tar or asphalt is not used on roofs which have an inclination of more than ¾ of an inch to 1 foot. Although roofs made with these materials have to be renewed every ten or twelve years, they are generally considered as satisfactory coverings when the felt and distilled pitch and asphalt used are of the best quality; and they also rank among the most inexpensive roof coverings for fire-proof buildings. The felt is put down directly on the concrete, the construction not differing any from that used over wood.

Many architects are of the opinion that vitrified or slate tiles when laid over four or five plys of tarred felt are the best materials to use for flat roofs of fire-proof buildings.

The dimensions of the vitrified tiles are about 8 by 8 by 1½ inches, and of the slate tiles 12 by 12 by 1 inch. The tiles are laid in cement mortar on the felt, which is put down and mopped over the same as for gravel roofs.

6. SUSPENDED CEILING CONSTRUCTION IN FIRE-PROOF BUILDINGS.

465. GENERAL DESCRIPTION.—In office-buildings having flat roofs there is generally an air-space or attic between the roof and ceiling of the upper story, varying from 3 to 5 feet in height. This space is often utilized for running pipes, wires, etc. Buildings having pitched roofs necessarily require a ceiling below to give a proper finish to the rooms in the upper story and to make these rooms comfortable. In office-buildings the ceiling under the roof is generally of a similar construction to that of the floors, although with some systems only the suspended ceiling slabs are required between the roof beams, and the latter may be made very light.

Under pitched roofs generally, and under flat roofs occasionally, suspended ceilings are used. T-bars, usually 3 by 3 inches in size, are hung from the roof construction by means of light rods, and the ceiling constructed either with wire or expanded-metal lathing laced to light angles or to flat bars placed between the T's, or with thin tiles of semi-porous or porous terra-cotta. The shape of the tiles should be such that they will drop below the flanges on the T's, so as to protect the metal.

Fig. 398 shows a section of porous ceiling tiles and Fig. 399 of semi-porous ceiling tiles. The width of the porous tiles is 16 inches

for 2-inch tiles, and 18, 20 and 24 inches for 3-inch tiles. The 2-inch tiles weigh 11 pounds and the 3-inch tiles 15 pounds per square foot, exclusive of the plastering. The tiles shown in Fig. 399 are 3 inches thick and weigh 4½ pounds per square foot.

Suspended ceilings of wire lath and plaster weigh only about 12 pounds per square foot, including the plastering.

Whether tile or metal lathing is used for the ceiling, the webs of

Fig. 398. Typical Solid Porous Ceiling Tile.

the T's should be covered with plaster or cinder concrete, to protect them from heat.

See also Fig. 395, which indicates one form of construction of suspended ceilings, with 1 by 3/16-inch hangers, 1¾ by 3/16 flat irons, wire lathing and plaster, and ¼-inch steel rods woven into the lathing to stiffen it.

Fig. 400 shows some detail sections, through suspended ceilings under roof, with metal lath and plaster and 1 by $\frac{3}{16}$-inch hangers bolted to 1½-inch angle-irons. Type 1 shows the ceiling hung from 1-inch channel-irons by the "White" patent clip, and type 2 shows it hung from 1-inch angle-irons by ¼-inch bolts. The "White" clips are made by the White Fire-proof Construction Company, of New York.

Other patented clips for fastening angle- and T-bars to I-beams

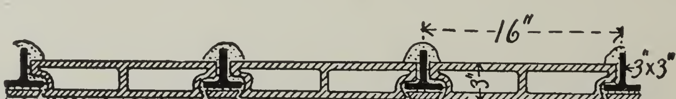


Fig. 399. Typical Hollow Ceiling Tile.

and channels are in use, and those patented by Mr. H. A. Streeter, of Chicago, are particularly useful in roof and suspended-ceiling construction, as they do away with all drilling, bolting, etc., and save much time in adjusting T-bars or other shapes to different widths of tiles.*

* For the safe loads which these clips will carry, see Kidder's "Architect's and Builder's Pocket-Book," Chapter XXIII.

7. FIRE-PROOF PARTITION CONSTRUCTION.

466. GENERAL CONSIDERATIONS.—The partitions considered are those of fire-proof buildings. They serve a twofold purpose: that of dividing extended spaces into rooms, and that of preventing the spreading of a fire. They are constructed of various materials, which, in addition to fire-resistance, should have the following properties: Poor conductivity of heat and sound; resistance to the effects of water; lightness in weight.

A fire-proof partition as a whole should have a rigidity which varies directly with its length and height, and also with its particular purpose and position. Fire-proofing considerations alone demand an absence of all door and window openings, and where these conditions obtain, the rigidity should be sufficient to withstand the destructive force of the heaviest streams of water from the fire hose. But many

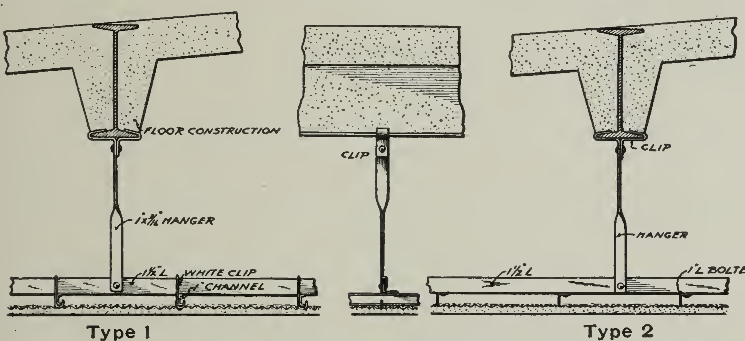


Fig. 400. Suspended Ceiling Under Roof.

partitions require communicating doors, and others, such as those of dark corridors, frequently have windows for lighting purposes. In partitions of this latter type great rigidity is considered unnecessary and even undesirable because of the difficulty of removing them or portions of them to stop a spreading fire.

The strength of a partition to resist vertical loads need be no greater than that required to sustain its own weight, unless it is a bearing partition; and very few partitions in fire-proof structures belong in the latter class.

Partition windows should have stationary fire-proof sash, fire-proof frames and wire-glass.

No materials should be used in the construction of partitions for fire-proof buildings which will not stand severe fire tests; and the

building bureaus of many cities will not allow their use if they have not thus satisfactorily passed such required tests.

467. DIFFERENT TYPES OF FIRE-PROOF PARTITIONS.—In a brief discussion of the different kinds of partitions generally used in fire-proof and fire-resisting buildings, it will be convenient to group them under several heads, according to the type of construction, the character and purpose of the structure, and the materials employed, as follows:

a. Brick Partitions.

b. Concrete Partitions.

1. Solid Monolithic Concrete Partitions.
   Stone or cinder, with or without reinforcement.
2. Concrete Block Partitions.
   Stone or cinder, solid or hollow blocks.

c. Plaster-block Partitions.

d. Terra-cotta Partitions.

e. Metal-and-plaster Partitions.

a. BRICK PARTITIONS.

468. GENERAL CONSIDERATIONS.—Experience proves that hard-burned common bricks make excellent fire-resisting partitions, which should be not less than 12 inches thick. These partitions are used almost exclusively as bearing partitions, as their weight and thickness make them inappropriate for non-bearing purposes.

b. CONCRETE PARTITIONS.

469. GENERAL CONSIDERATIONS.—Partitions of concrete may be subdivided as indicated in the preceding list of the different types. Compared with terra-cotta or metal-and-lath, concrete is seldom used, because of its great weight, the cost of the wood forms, if monolithic, and excessive thickness if not reinforced or if in the form of hollow blocks.

Of the two kinds of concrete, that made of cinders is the cheaper and lighter; and cinder concrete in the form of solid or hollow blocks, tongued-and-grooved on the edges, makes a partition material which passes the tests of city building bureaus. The usual sizes of the blocks are, height, 12 inches; length, 18 inches; thickness, 2½ and 3 inches. The thinner blocks are solid and the thicker ones hollow.

c. PLASTER-BLOCK AND WALL-BOARD PARTITIONS.

470. GENERAL DESCRIPTION.—The materials composing these partitions are various patented combinations of plaster of Paris, chemicals, reeds, fibers, asbestos, wood chips, cinders, etc., and are sold under different names. While they make the lightest partitions, and while they resist flame and the transmission of heat in an approved and often in a superior manner, they cannot be considered as ranking with the best of the fire-proof materials, as they do not always come up to the standards required in the tests of resistance to hose-stream destruction.

In addition to their lightness, they have the great advantages of relative cheapness, of being easily cut with a saw and of holding nails.

They are made either solid or hollow and from 2 to 4 inches thick, those 3 inches or more in thickness being hollow; and they are made with grooved, hollowed or rebated edges so that the mortar with which they are put together forms a bonding or tying dowel, spline or key. Sometimes, to further reinforce the partitions at the block joints, horizontal or vertical metal rods or metal dowels are inserted.

Plaster-blocks are usually laid up in mortar composed of lime-putty, one part; cement, two parts; and sand, two or three parts, although some are laid in lime mortar.

The following are the average weights per square foot of plaster partition blocks:

Thickness of blocks, in inches......	2	2½	3	3½	4	5	6	8
Weight in pounds per square foot..	7	8½	9½	10½	12	15	18	22

Plaster-boards average 1 inch in thickness and 4 pounds per square foot in weight.

To obtain the weight of a partition plastered on both sides there must be added to the weight of the partition as given above about 18 pounds per square foot.

*Scagliolinc Partition Blocks.**—These blocks are made of plaster of Paris, chemicals and well-burned cinders, and are furnished in sizes of 18 by 24 inches, 2, 3 or 4 inches thick. The approximate weight of a 3-inch block is 12 pounds per square foot.

Fig. 401 shows the general form of one of these blocks, and Fig.

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* Manufactured and patented by the Fire-proof Partition Company, 1 Madison Ave., New York.

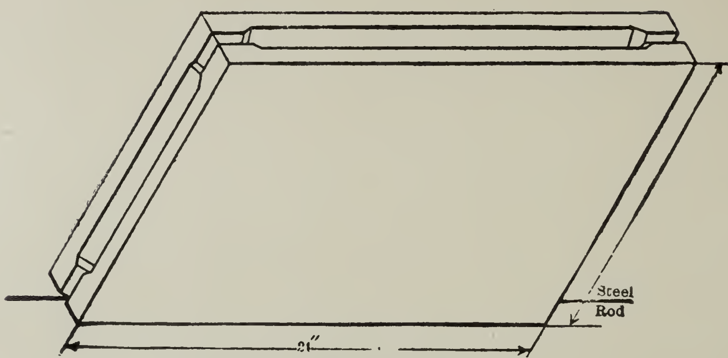


Fig. 401. Scaglioline Partition Block.

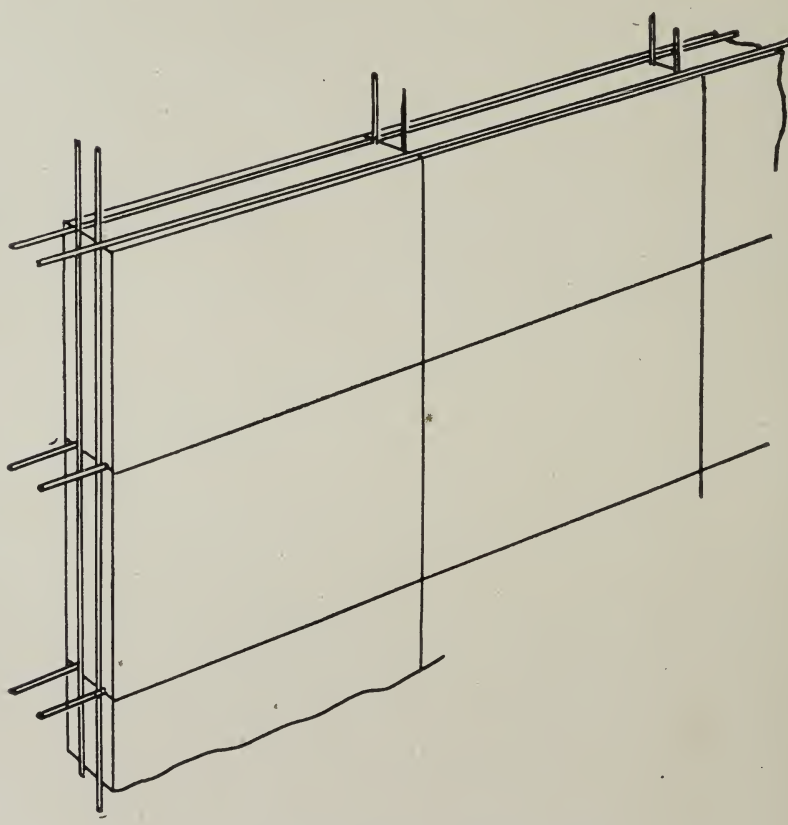


Fig. 402. Ellendt Reinforced Block Partition.

402 shows the most recent improved method of constructing them and building them into a rigid and light partition wall by the use of light continuous reinforcing rods or wires running horizontally and vertically as shown. This construction is known as the "Ellendt Reinforced Block Partition."

*Gypsite Partitions.**—The materials used are mainly pure gypsum and a specially prepared strong and tough interlacing fiber. Two systems of partition construction are used—the "tile construction" and the "solid construction." In the former, gypsite tiles, 1 inch thick and in two thicknesses, separated, are securely bonded by means of staff uprights 12 inches on centers, cast in place between the inner faces of the tiles. In the latter the partition is constructed by pouring the material in liquid form about a framework of channel-iron verticals with wood nailing-blocks wired thereto, the metal and wood being completely imbedded in staff.

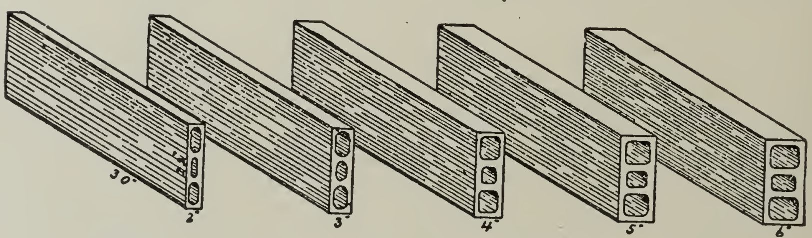
Mackolite Partition Tile.†—The basis of mackolite, an invention of Messrs. A. and O. Mack, of Ludwigsburg, Germany, is gypsum, which is calcined, ground, mixed with certain chemicals, reeds and fibers, and then poured into molds, left for about one-half hour to set, and then kiln-dried for four days. The thicknesses of the blocks or tiles are 3, 3½, 4, 6, 8 and 12 inches; the height of all, 12 inches; and the length, 48 inches for the 3-, 3½- and 4-inch blocks, and 30 inches for the others. Fig. 403 shows the general shape of these mackolite hollow blocks. They are made also with grooved edges. They are laid to break joints in courses as shown in Fig. 404, and are fitted around openings and angles by being cut with a saw.

"U. S. G." Fibered Plaster Partition Blocks.‡—These blocks are made of a high grade of plaster of Paris, combined with cocoanut fiber for toughness, and are either solid or hollow, in standard units of varying thickness for different purposes. They have been used for partitions in some recent important fire-proof buildings, and are very light in weight, easy to put up, resistant to the passage of sound, and easily cut with a saw or nailed into.

Gypsinite Partitions.§—Although these partitions are not strictly plaster-"block" partitions, they may be mentioned here conveniently.

* Manufactured and patented by the Detroit Fire-proofing Tile Company, Pittsburg, Pa.
† Manufactured and patented by the Mackolite Fire-proofing Company, Chicago, Ill.
‡ Manufactured and patented by the United States Gypsum Company, New York.
§ Manufactured and patented by the Gypsinite Company, New York.

The partitions consist of studs made of wood strips imbedded in and protected by the gypsinite which is a plaster composition. These gypsinite studs are usually set 16 inches on centers, bridged similarly to wood studding and covered with plaster-boards and plaster or with metal lath and plaster, as shown in Fig. 405. They are secured to floor and ceiling either by channel-irons or by gypsinite



Showing 2 in., 3 in., 4 in., 5 in. and 6 in. Hollow Mackolite partition tile 30 inches long.

Fig. 403. Mackolite Hollow Partition Blocks.

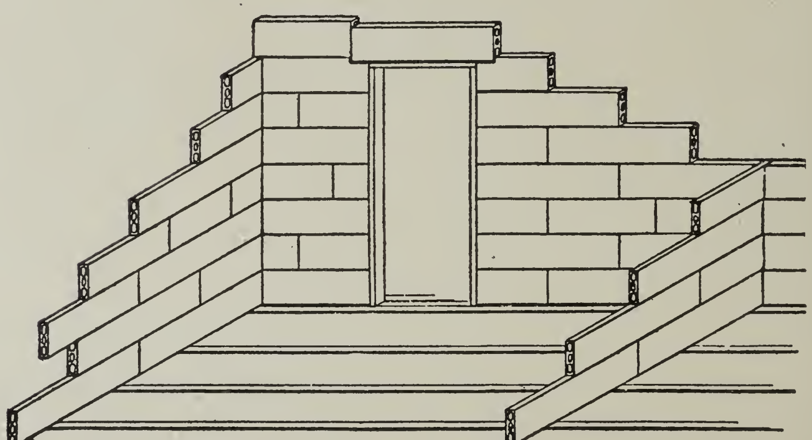


Fig. 404. Mackolite Partitions.

sills and plates nailed to the fire-proofing. The average total thickness of the partition is about 4½ inches, the stock sizes of the studding 3 by 3 inches by 12 feet, and the weight of studs 3 pounds to the foot.

The principal advantages claimed for these partitions are their sound-proof property, their stiffness and strength, their light weight,

their adaptation to the passage of pipes, low cost and nail-holding properties.

There are other excellent partition plaster-blocks besides those already mentioned, but it is not possible to refer to them all.

*Sackett's Wall-Board or Plaster-Board.**—This is made in 32 by 36-inch sheets about ¼ of an inch thick, of alternate layers of strong wool felt and plaster, and is nailed directly to the studding,

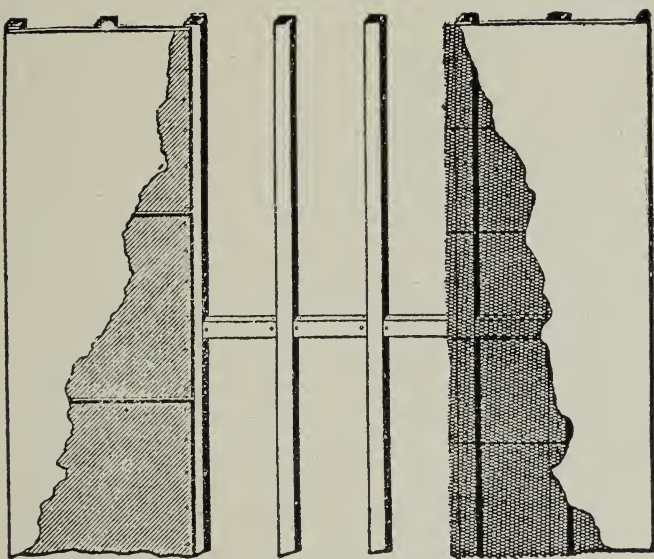


Fig. 405. Gypsinite Partition.

which is set 16 inches on centers. For cutting and fitting an ordinary saw is used; and for nailing, 1¼-inch wire nails with large heads, set from 4 to 6 inches apart, each nail being driven home firmly and tightly to prevent any working under the plaster coat. The boards are spaced ¼ of an inch apart, breaking joint horizontally on the walls and at right-angles to the furring on the ceiling.

The best plastering results are obtained by first thoroughly filling the joints between the boards and then applying a brown coat, from ¼ to ⅜ of an inch thick, of any good brand of hard wall plaster. When the first coat is thoroughly set, it is finished with a thin coat of regular hard finish, lime putty and plaster, or a patent ready finish.

* Manufactured and patented by the Sackett Wall Board Company, New York.

This plaster-board has been widely used in many important buildings, and the principal advantages claimed for it are its freedom from shrinking, warping and buckling; its fire-resistance; its lightness; the reduction in the amount of water used in plastering on account of the smaller amount of plaster needed; and its lower cost for the same reason, when compared with metal lath.

Plaster-boards are made also of greater thickness than the above-mentioned Sackett's boards, the thickness running from ½ of an inch to 2 inches.

d. TERRA-COTTA PARTITIONS.

471. GENERAL DESCRIPTION.—In addition to the fire-resisting qualities of terra-cotta partitions, they are lighter than those of brick or concrete, strong, easily erected by bricklayers, and do not transmit heat, cold or sound to any great extent.

About 15 per cent of the quantity of blocks required should be of full porous material for the nailing of the wood trim. In school-houses, where blackboards have to be fastened on the walls, all of the blocks should be full porous. These are slightly more expensive, but make a better partition for any purpose. All partitions and furring blocks, unless otherwise specified, are scratched to receive plastering. If the surface is to be whitewashed the blocks are made smooth.

Wood or channel-iron bucks are placed in all doorway openings. These should be 1½ inches wider than the thickness of the blocks, as they act as grounds for the plastering.

It is not generally practicable to use 2-inch blocks for partitions, except for closets, shafts, etc., unless they are reinforced by metal. Where room must be economized the "New York" reinforced partition may be employed, using 2-inch partition blocks with the truss wire in the horizontal joints. This is the Bevier patent, and made by the National Fire-proofing Company, Pittsburg, Pa. See Fig. 409.

Three-inch partition blocks can be safely used up to 12-feet, 4-inch to 14-feet, and 6-inch to 20-feet heights.

The blocks are commonly made 12 inches high by 12 inches long, although some prefer to have them 8 inches high. They may be brick-shape also. They can be made any size required, but special sizes are necessarily more expensive.

In office-buildings it is good practice to have all the main corridor, stairway and elevator enclosures of 4-inch and the partitions between rooms of 3-inch blocks. Partitions should be bonded where meeting and anchored to wood bucks or brick walls by using ten-penny nails in at least every second joint.

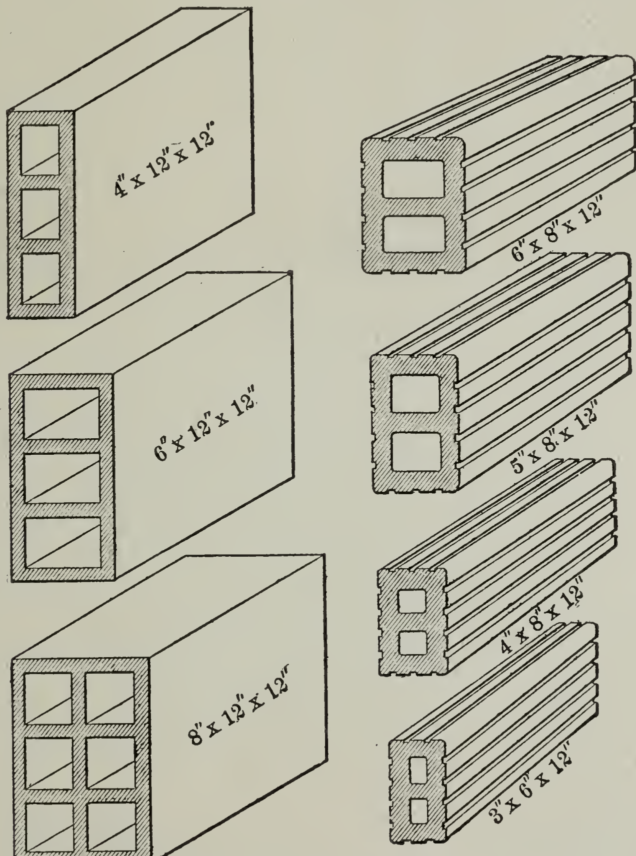


Fig. 406. Terra-cotta Partition Blocks.

When required for outside walls exposed to the weather, the blocks should be of specially made dense, hard-burned material. These are made smooth on the outside face and do not require plastering. They should not be less than 6 inches thick unless reinforced.

Fig. 406 shows some terra-cotta partition blocks in typical shapes,

the four figures on the right side of the drawing being the brick-shaped blocks. The voids are usually in a horizontal position in a partition, and the pieces are set to break joints horizontally.

The mortar generally used is made of lime-putty, one part; cement, two parts; and sand, two or three parts.

Fig. 407 shows partition blocks with circular and angular corners, in which the voids are in a vertical position in the wall.

Fig. 408 shows a 2-inch "Phœnix" partition made of terra-cotta blocks reinforced with light band-iron, manufactured by Henry Maurer & Son, New York, and patented. The iron greatly increases the rigidity of the partition. It is hardly practicable to use 2-inch terra-cotta partitions unless they are fortified or reinforced in some such way as this.

Fig. 409 shows the general form of the "New York" partition, Bevier patent, with the wire truss reinforcement.

The weights of porous, semi-porous and dense terra-cotta partitions vary as follows:

2-inch partition, 10 to 14 pounds per square foot;
3-inch partition, 12 to 16 pounds per square foot;
4-inch partition, 13 to 19 pounds per square foot;
5-inch partition, 20 to 22 pounds per square foot;
6-inch partition, 22 to 23 pounds per square foot;
8-inch partition, 28 to 33 pounds per square foot.

Ten pounds per square foot must be added to these weights, if plastering on both sides is to be included.

e. METAL-AND-PLASTER PARTITIONS.

472. GENERAL DESCRIPTION.—These partitions consist of some form of metal lath, generally with, but sometimes without, metal studding, plastered on both sides, solid or hollow and with or without a cinder concrete core. Those with metal studs, made solid and finishing about 2 inches thick, have been the most extensively used.

The advantages are: good resistance to the passage of fire; saving of room; great stiffness; and very light weight in proportion to strength.

The disadvantages are: strong tendency for the plaster to be washed off by the water from the fire hose and for the lath to become exposed; tendency for the lath, even when painted, to be injured by corrosive properties of the plaster; and objections on

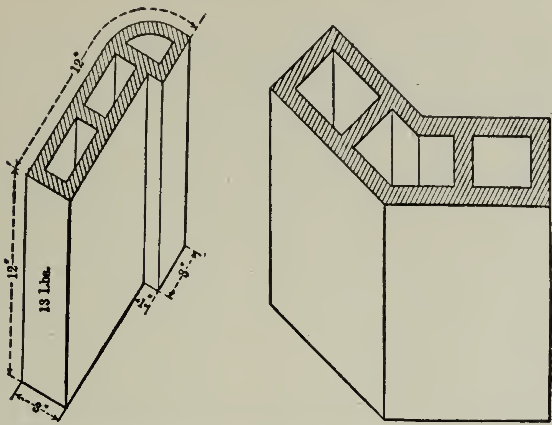


Fig. 407. Partition Blocks. Circular and Angular Corners.

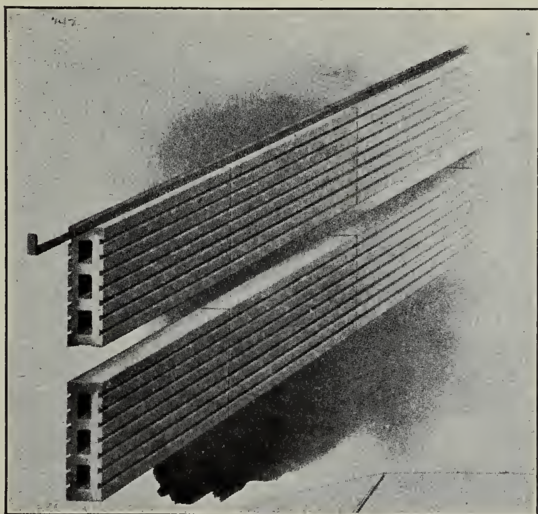


Fig. 408. Phoenix Partition.

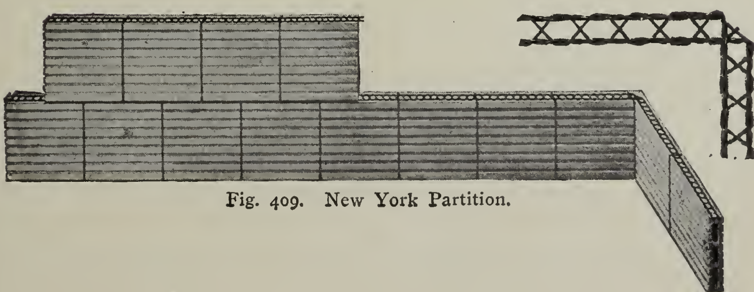


Fig. 409. New York Partition.

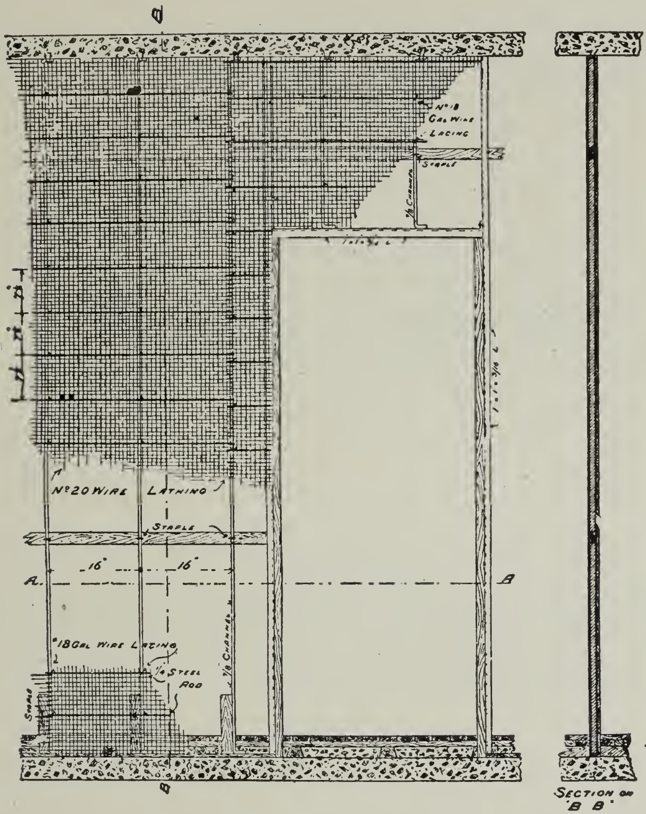
the part of fire underwriters to too great resistance of the lath to any necessary cutting through in case of fire.

In estimating the weights of metal-and-plaster partitions, it is usual to allow 120 pounds per cubic foot for plaster and 96 pounds per *cubic* foot for lightly tamped cinder concrete; but the average solid 2-inch partition, dried out, may be conveniently figured directly at about 20 pounds per *square* foot.

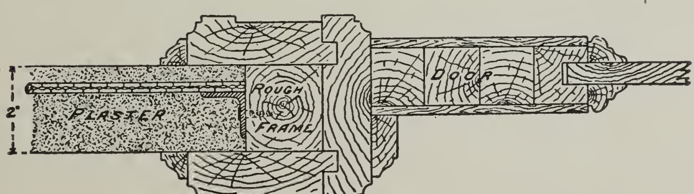
There are two general types of metal-and-plaster fire-proof partitions: (1) the "Single" Solid Partition and (2) the "Double" Partition, which may be solid or hollow. Their construction is briefly described in the following articles.

473. GENERAL CONSTRUCTION OF "SINGLE" SOLID METAL-AND-PLASTER PARTITIONS.—Fig. 410 shows an elevation and two sections of a typical "single" solid metal-and-plaster partition, the one shown being a 2-inch partition, together with section of typical wood trim. The following are the principal construction data: Studs usually ⅞- or 1-inch channel-irons or other convenient sections, placed 12 inches on centers for heights over 10 feet, and 16 inches for heights under 10 feet; studs fastened at lower ends by bending and punching the latter and by nailing them to strips of wood fastened to the floor beams or fire-proofing, said strips being used as a more resisting material in allowing for the expansion caused by fire; studs fastened at upper ends by nailing them to the fire-proofing or by wiring them to the ceiling metal; framing of openings usually 1 by 1 by 3/16-inch angle-irons, to which are fastened the rough wooden frames, with No. 12 screws through holes bored 16 inches on centers; metal-lathing of appropriate kind and weight secured to one side of studs with No. 18 galvanized-wire lacing at the crossings of ¼-inch steel stiffening rods placed horizontally about 7½ inches on centers; wood grounds put on where required, by fastening them with staples to the studs; five coats of some approved hard-setting wall-plaster put on the metal-lathing, including one scratch coat on one side, one brown coat on both sides and one white coat on both sides; a finished trim of wood or other material nailed or otherwise fastened to the rough frame.

474. GENERAL CONSTRUCTION OF "DOUBLE" METAL AND PLASTER PARTITIONS.—In this classification a "double" partition means one in which the metal lath is fastened



Enlarged Section on A A



Typical Section of Wood Trim.

Fig. 410 Single Solid Wire-lath Partition.

on both sides of the metal studs. These partitions may be either solid or hollow. Only electric wires and pipes of not much over ½-inch diameter can be run in 2-inch solid partitions, and thicker ones must consequently be built if they are to conceal larger pipes. In

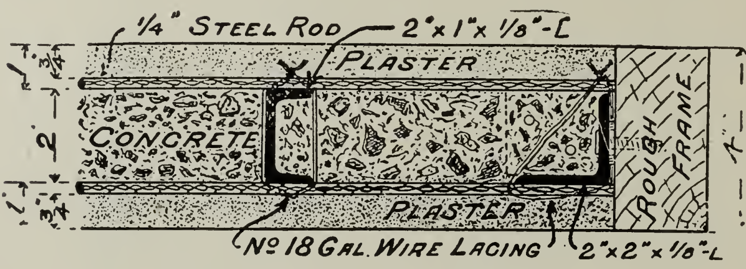
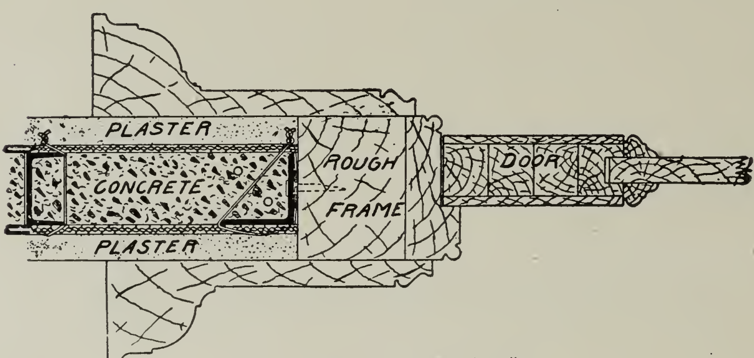


Fig. 411a. Double Solid Wire-lath Partition.



Typical Section of Wood Trim.
Fig. 411b. Double Solid Wire-lath Partition.

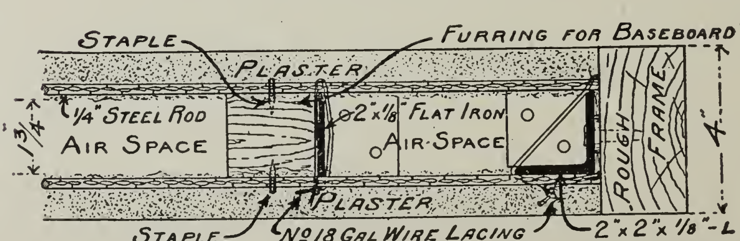


Fig. 412. Double Hollow Wire-lath Partition.

this latter case rolled or sheet-steel channels, 2-, 3- or 4-inch, are used.

In double solid partitions the inside space between the two layers of metal lath is often filled in with cinder concrete, into which

nails can be driven, thus doing away with the necessity of wood furring.

Figs. 411*a* and *b* show horizontal sections through such double solid partitions, finishing, when plastered, 4 inches thick. A typical construction for a door trim is shown also. A partition of this kind has great fire-resistance and strength.

Fig. 412 shows the construction of a double hollow 4-inch partition. In this type an air-space is left, no core or mortar or concrete being put between the studding and lathing. The cost is greater than that of a single solid partition of less thickness, and the fire-resistance is not so good.

The spacing of 2-inch studs in hollow partitions is usually 12 inches on centers for heights of 16 feet or more and 16 inches for heights less than 16 feet.

475. THE BERGER PRONG-LOCK STUDS FOR METAL-AND-PLASTER PARTITIONS.—*General Description.*—Fig. 413 shows a form of studding made and patented by the Berger Manufacturing Company, of Canton, Ohio, and known as the "Berger Prong Lock Wireless System of Steel Studding for Fire-proof Walls and Partitions." It is used also for furring walls, ceilings, etc.

It is made in various sizes, from No. 20, No. 18 or No. 16 gauge sheet-steel, and in several different shapes, such as channels, T's, L's, U's and Z's, with necessary fastenings for the top and bottom.

The marked advantages possessed by these studs and furring strips is the provision for attaching the metal lath. For this purpose prongs are punched out on the face of the studs and stand at right-angles to the faces from which they are punched, ready to receive the lath. In applying the latter these prongs pass through the meshes and are clinched over them with a hammer, thus holding the lath firmly and securely and leaving a true surface for the plasterer to work on. Angle-irons may be used for turning all corners. The "Z"-strip, "U"-strip, "L"-strip or a special furring strip may be used for suspended ceilings or for ceilings applied directly to the under side of the floor beams with specially designed clips. Similar members are manufactured for light structures of all kinds.

Spacing of Studding.—For 2-inch solid partitions with ⅞-inch rolled channels or 1-inch Prong-lock Studs, the channels or studs should be placed 12 inches on centers when the height of a story

exceeds 10 feet. When the height of a story is less than 10 feet, a spacing of 16 inches will answer. For hollow partitions with 2-inch studs the latter can be spaced 16 inches on centers for story heights of 16 inches and less. For greater heights they should be placed 12 inches on centers.

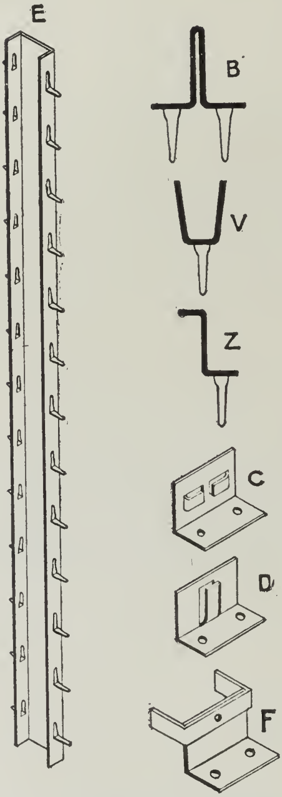


Fig. 413. Berger Prong-lock Stud and Fastenings

Weight.—The weight of a 2-inch solid partition is about 20 pounds per *square* foot, when dry. The weight of partitions of greater thickness may be estimated on a basis of 120 pounds per *cubic* foot for plaster and 96 pounds for cinder concrete, slightly tamped.

Cost.—The cost of 2-inch solid partitions ranges from 16 to 20 cents per *square* foot, including plaster.

476. RIB-STUDS FOR METAL-AND-PLASTER PARTITIONS.—Fig. 414 shows a form of studding made and patented by the Trussed Concrete Steel Company, of Detroit, Mich., and called "Rib-studs;" and shows also the application of such studs and of "Rib-lath," which is made on the same principle, to hollow partitions, in this example in connection with hollow tiles and the Kahn system of reinforced concrete floors. These studs consist of a series of straight ribs, or main tension members, connected by light cross ties which act as spacers, provide a mechanical bond and resist shrinkage and temperature stresses. The method of fastening them in place is shown in the figure. They are made in 1⅙-, 2¼-, 3¼- and 4¼-inch widths, and also in additional widths, if required, up to 8½ inches. They can be made in any length up to 20 feet.

477. ALLUNITED STEEL STUDDING FOR METAL-AND-PLASTER PARTITIONS.—Fig. 415 shows a form of studding made and patented by the General Fire-proofing Company, of Youngstown, Ohio, and called the "Allunited Steel Studding." The

studs are made with side slots for solid partitions, and with middle slots, as shown, for double-lathed partitions, and are secured in place at top and bottom by bending and nailing. The pieces are rivetted together, holes being left in the horizontal braces for spacing studs

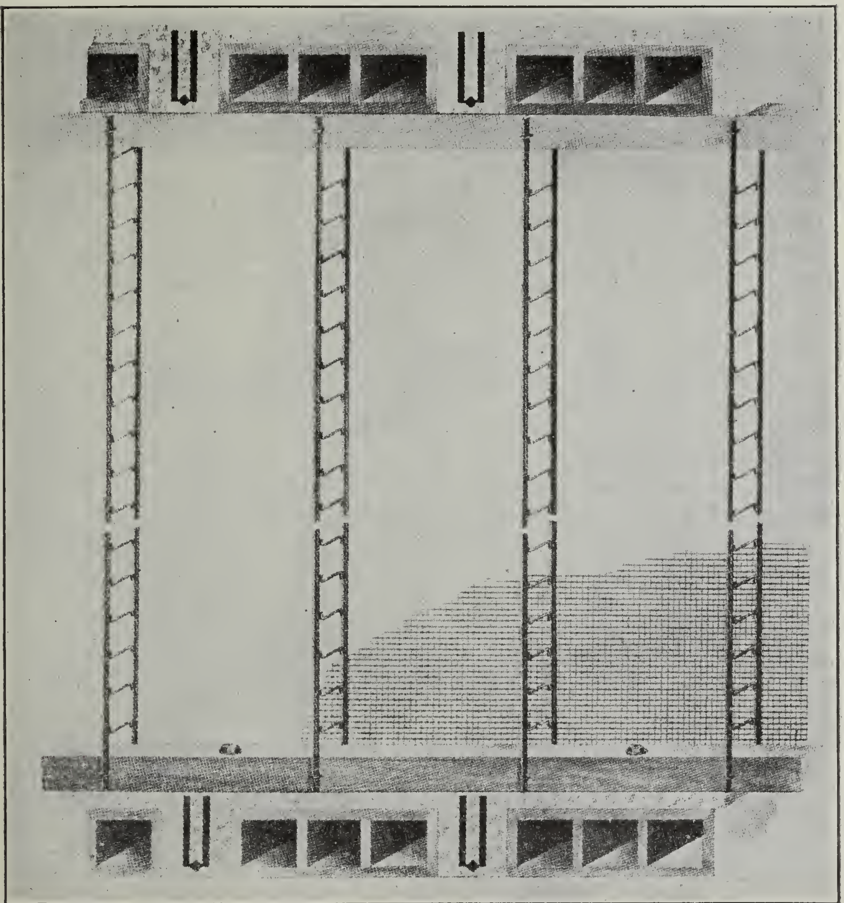


Fig. 414. Rib-studs for Partitions.

either 12 or 16 inches on centers. Fig. 416 shows the manner of holding wood blocks for grounds for base, chair-rail, picture-mold, etc., or for plaster grounds to insure proper thickness of the plastered wall. For solid partitions these studs are made in widths of ⅞, 1 and 1¼ inches; for double-lathed hollow partitions, in widths

of 2, 2¼, 2½, 3 and 3½ inches. No. 16-gauge steel is used, and the weights vary from 1¾ to 7 pounds per square yard.

478. METAL-AND-PLASTER PARTITIONS WITHOUT STUDDING.—There are several types of metal-and-plaster partitions which can be put up without the use of studs.

Figs. 417 and 418 show two varieties of one type of solid studless metal-and-plaster fire-proof partitions, in which the "Triangular Mesh Steel Fabrics," made by the American Steel and Wire Company, of Chicago, are used. In the 6-inch partition indicated in

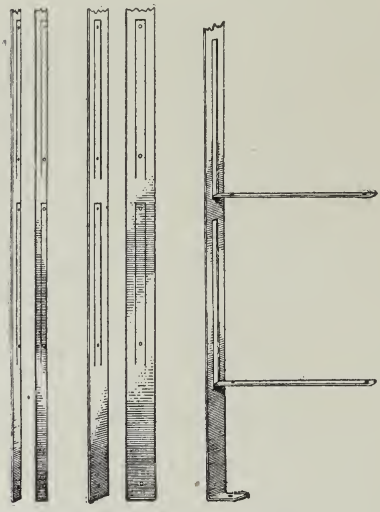


Fig. 415. Allunited Steel Studding.

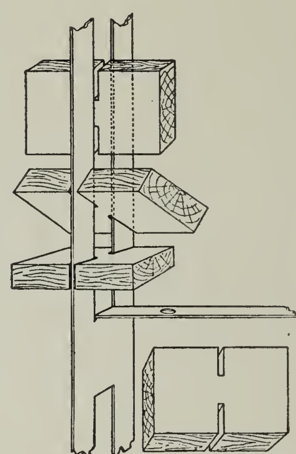


Fig. 416. Allunited Steel Studding and Grounds.

Fig. 417 the triangular mesh fabric is placed in a vertical position in a rectangular-fret form, the method of weaving the longitudinal and cross wires being such as to allow this position. The result of the finished construction is a very good solid stiff partition. Fig. 418 shows a different arrangement of the fabric, zigzag in plan, for thinner partitions, the illustration being for a 3-inch thickness. The materials used for plastering may be any of the approved plastering compositions, or stone or cinder concretes.

Fig. 419 shows the "Truss Metal Lath," Kühne patent, manufactured by the Truss Metal Lath Company, of New York, and used in the construction of solid strong and very rigid partitions, one form of which is shown in Fig. 420. It belongs to the class of

expanded-metal laths, and is very highly recommended in the matter of taking and holding mortar, and of resistance to fire and to hose streams. It is made from soft steel, of Nos. 24, 26 and 28 gauges, in sheets varying in width up to 30 inches, in length up to 9

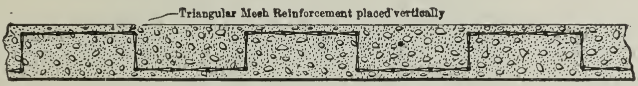


Fig. 417. Triangular Mesh Fabric. Six-inch Partition.

feet 4 inches, and with a thickness of about 1 inch. It may be obtained either black or galvanized. Fig. 420 shows sections through a "Truss Metal Lath" partition and through jamb and head-casing of door, with the lath secured to a flat iron frame of the same width as the finished partition. To this iron frame a smaller flat iron is

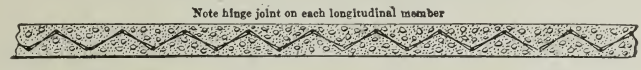


Fig. 418. Triangular Mesh Fabric. Three-inch Partition.

bolted, with pipe separators, to which the lath is fastened, allowing the plaster or concrete to surround the iron. The wood trim is secured in place as shown.

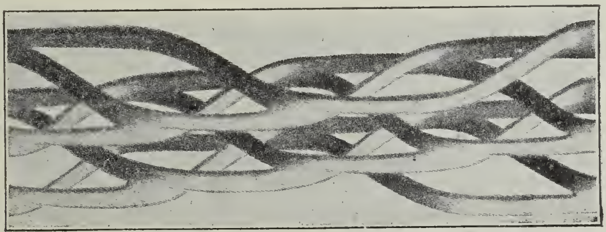


Fig. 419. Truss Metal Lath.

Fig. 421 shows another form of metal-and-plaster solid partition in which the "Ferroinclave" thin steel corrugated sheets, made by the Brown Hoisting Machinery Company, of Cleveland, Ohio, are used.

479. DIFFERENT KINDS OF METAL LATH FOR PLASTERED PARTITIONS.—The many varieties of metal lath manu-

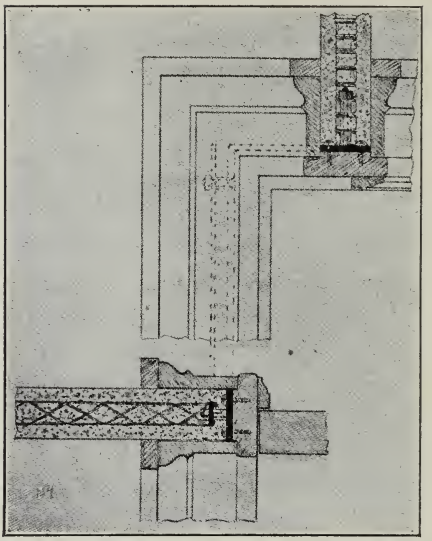


Fig. 420. Truss Metal-lath Partition and Trim.

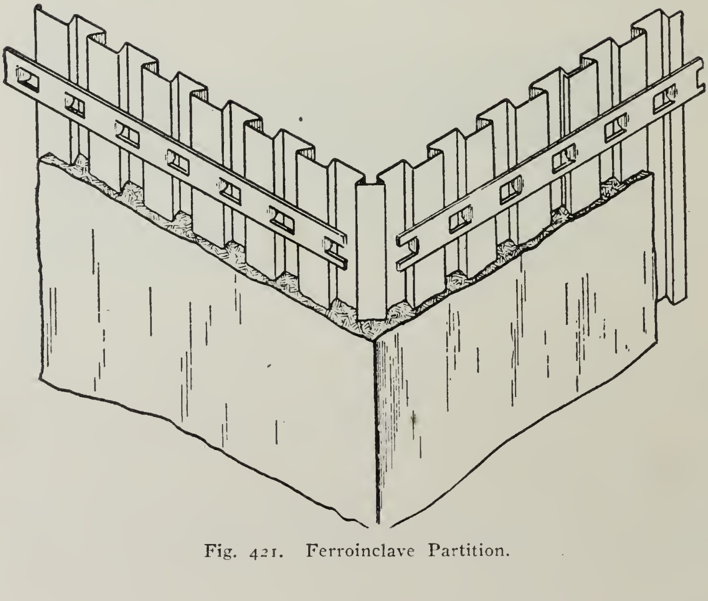


Fig. 421. Ferroinclave Partition.

factured to suit different constructive necessities and plastering requirements may be conveniently classified as follows:

1. Wire Lath.
   (1) Unstiffened or "plain."
   (2) Stiffened.
      a. With corrugated steel furring strips.
      b. With round rods.
      c. With V-shaped stiffening ribs.
2. Expanded-metal Lath.
   (1) *a.* "A" and "B" Lath.
      b. Diamond Mesh Lath.
   (2) Herringbone Lath.
   (3) Imperial or Spiral Lath.
3. Perforated Sheet-metal lath.
   (1) Bostwick Steel Lath.
   (2) Kühne's Clincher Lath.
   (3) Rib Lath.
   (4) Miscellaneous forms.
4. Other forms already mentioned, such as
   (1) Welded Fabric or Mesh.
   (2) Lock-woven Fabric.
   (3) Steel Wire Fabric.
      a. Triangular Mesh.
      b. Square Mesh.
   (4) Miscellaneous forms.

480. 1. WIRE LATH OR WIRE CLOTH.—Regarding *unstiffened or "plain"* wire lath or wire cloth the following are the principal facts: Wire commonly used, No. 17 to No. 20 gauge; number of meshes, generally 2½ by 2½ to the square inch; usual widths, 32 and 36 inches, some manufacturers, however, furnishing it in any width up to 8 feet; finish of lath, unpainted or "bright," painted or galvanized, the last two being used with patented hard-plaster compositions; stiffness greatly increased by galvanizing, the wires being zinc-soldered together at their intersections; tendency to corrosion before plastering lessened by galvanizing; all wire lathing tightly stretched to give tight, stiff surface for plaster.

Data for *stiffened* wire lath:

In all varieties the stiffeners run at right-angles to the bearings. The best-known wire laths are the "Clinton" and the "Roebling."

The Clinton stiffened wire lath is made from 18- to 22-gauge wire, either japanned or galvanized, in 100-yard rolls, in 32- or 36-inch widths, and is stiffened either with corrugated steel furring strips fastened with metal clips crosswise about every 8 inches, or with round rods, varying in diameter from 1/8 to 1/4 of an inch and in spacing on centers from 8 to 12 inches. With the corrugated stiffeners no other furring strips are needed.

The Roebling standard stiffened wire lath is made of No. 20 plain wire cloth, generally painted, but furnished also bright or galvanized, in 36-inch widths for beams or studs spaced 12 inches on centers and in 32- or 48-inch widths for 16-inch spacing. The proper widths should always be ascertained before ordering. The stiffening is accomplished by means of V-shaped ribs made of No. 24 sheet-steel, either 1/2 or 1 inch deep and woven in, about 7 1/2 inches on centers. The wire lath with the 1/2-inch ribs is used on woodwork, no furring being necessary and the lath being fastened by driving steel nails through the angle of the V's; and the lath with the 1-inch rib is used as a combined furring and lathing, on exterior walls, for example, an air-space being thus provided between the plaster and the wall. The Roebling Construction Company make also a metal lath called the "solid-rib stiffened wire lath," in which the V-ribs are replaced by 3/16- or 1/4-inch solid steel rods, and which is used when required to be applied to light metal furring. It is fastened to the latter by lacing wire. Both the plain and stiffened Roebling wire laths are made with 2 1/2 by 2 1/2 meshes to the square inch for ordinary lime-and-hair plaster, and with 3 by 3 and 2 1/2 by 4 meshes for hard wall plasters and for thin partitions. The 2 1/2 by 4-mesh lath is known commonly as "close-warp" lath.

Fig. 422 shows the unstiffened and Fig. 423 the stiffened Clinton wire lath.

Fig. 424 shows the Roebling No. 18 wire 2 by 2 and 2 1/2 by 2 1/2-mesh and the No. 20 wire 2 1/2 by 4-mesh wire lath.

Fig. 425 shows the Roebling Standard stiffened wire lath, the plaster applied to part of it and the manner in which nails are driven through the V-ribs to secure the lath in place.

481. 2. EXPANDED-METAL LATH.—This material, controlled by the Associated Expanded Metal Companies, and with offices under various names in the principal cities, has been used very extensively both for lathing on wood construction and for

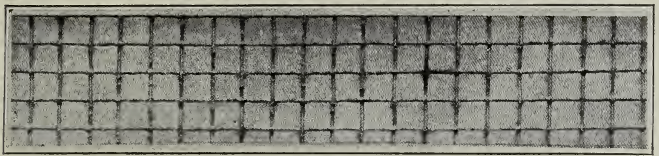


Fig. 422. Clinton Wire Lath, Plain.

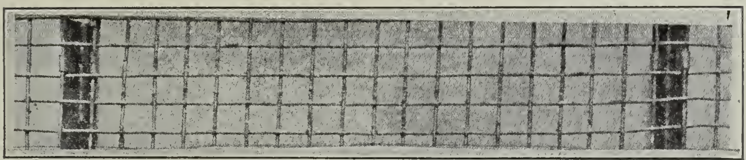


Fig. 423. Clinton Wire Lath, V-stiffened.

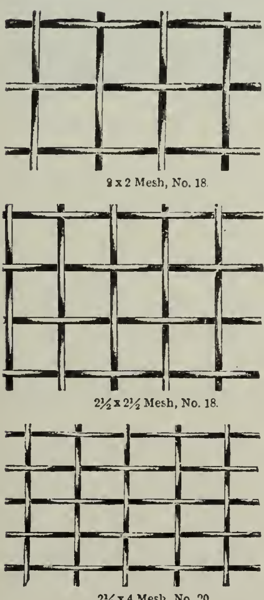


Fig. 424. Roebling Wire Lath, Plain.

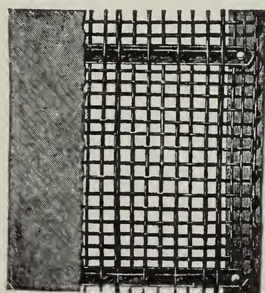


Fig. 425. Roebling Stiffened Lath.

fire-proof work. It is made from strips of thin, soft and tough steel by a mechanical process which pushes out or expands the metal into oblong meshes, and at the same time reverses the direction of the edges, so that the flat surface of a cut strand is nearly at right-angles with the general surface of the sheet. The lath being flat and of considerable stiffness, does not require to be stretched, and can be fastened directly to the under side of floor joists or to wood studding. If used on planks it should be fastened over metal furring strips. When applied to studding the lath should be placed so that the long way of the mesh will be at right-angles to the studding, as this insures the greatest rigidity. The studding or furring strips should be spaced 12 or 16 inches on centers, and the lathing secured with staples 1 inch long, driven about 5 inches apart on the studs or joists. The lath, when applied,

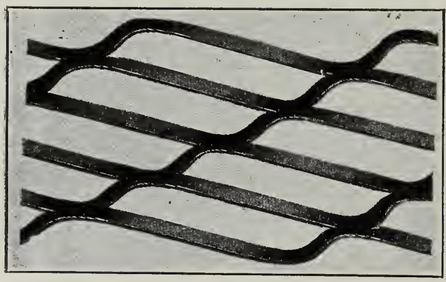


Fig. 426. "A" and "B" Expanded-metal Lath.

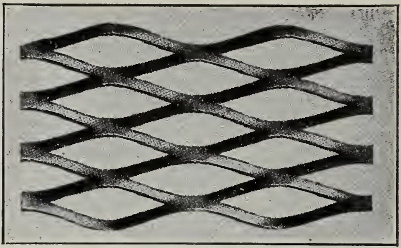


Fig. 427. Diamond Expanded-metal Lath.

is a scant ¼ of an inch in thickness, and to obtain a good wall ½-inch grounds should be used.

There are two varieties of the first of the three classes of expanded-metal lath used for plastering and mentioned in the classification, both being made in sheets 8 feet long and from 18 to 24 inches wide. Fig. 426 shows the *"A" and "B" expanded-metal lath,* usually of 0.6 by 1.5 inches mesh and 24 and 27 Stubbs' gauge; and Fig. 427 shows the *"Diamond Mesh" expanded-metal lath,* usually of 0.41 by 1.2 inches mesh and 24 and 26 Stubbs' gauge.

The *"Herringbone"* expanded-metal lath is a later improved form, made in four varieties or grades, known respectively as *"AA," "A," "BB"* and *"B."* The *AA* grade is the stiffest and can be used on studding spaced 16 inches on centers. It is the most expensive of the four grades. The *A* grade has a larger mesh and is not as stiff

as the *AA* grade. It is better to have the studding spaced 12 inches on centers, although 16-inch spacing can be used. It is the grade most used. These two grades are the ones used for lathing ceilings, and should be specified as "*AA* flat" or "*A* flat," which means that the short cross ribs are turned after being "expanded," thus diminishing the size of the key and offering a larger surface for supporting the plaster.

The *BB* and *B* grades are made in wider sheets, are more open, and are not as heavy nor as stiff as the *AA* and *A* grades. Both, as in the case of the *A* grade, should have the studs set 12 inches on centers. The *B* grade has a larger mesh and is not as stiff as the *BB* grade.

Fig. 428 shows the general forms of grades *BB* and *A* of the herringbone expanded-steel lath, and Fig. 429 shows a fire-proof

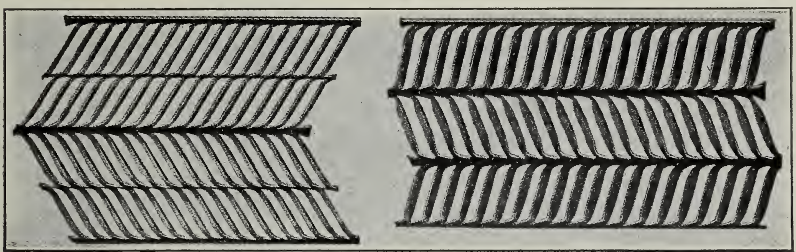


Fig. 428. Herringbone Expanded-metal Lath.

hollow partition with herringbone lath on the "allunited" steel studding, and also with the "Universal" steel corner-bead made by the General Fire-proofing Company. Fig. 430 shows this corner-bead in detail.

Great stiffness is given to this lath by the heavy longitudinal ribs which are at an angle of about 45° to the original surface of the sheet. The sheets are placed at right-angles to the joists or studding, and set in such a way that the longitudinal ribs slope *down* against the studding and thus take a better hold of the plaster. Fig. 431 shows in section the right and the wrong way to apply the lath. No. 12 or 14 "poultry" staples are generally used to fasten this kind of lathing to wood.

The "*Imperial*" or "*Spiral*" expanded-metal lath, made by the Imperial Expanded Metal Company, of Chicago, and shown in Fig. 432, is a somewhat lighter and less expensive lath, and has been

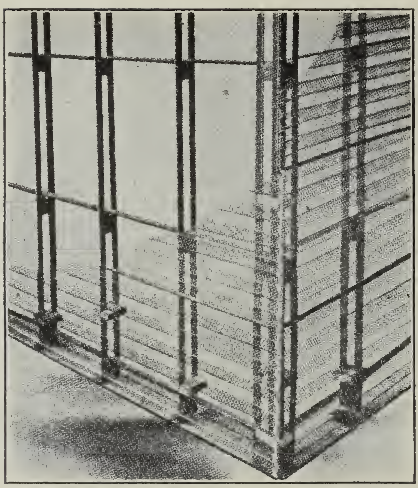


Fig. 429. Herringbone Lath on "Allunited Steel Studding.

used lately in large quantities and is well recommended by plasterers. It is sold in sheets 48½ inches long by 16 inches wide, and in bundles of 25 sheets. It is used for solid and hollow partitions, is easily handled and quickly put on, and the spiral twist makes a good bond, as there is an excellent clinch.

482. 3. PERFORATED SHEET-METAL LATH.—

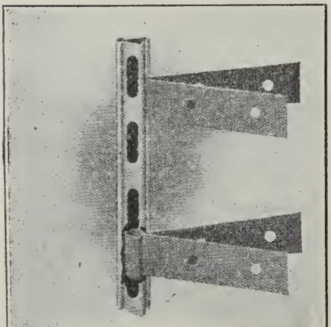


Fig. 430. Universal Steel Corner-bead.

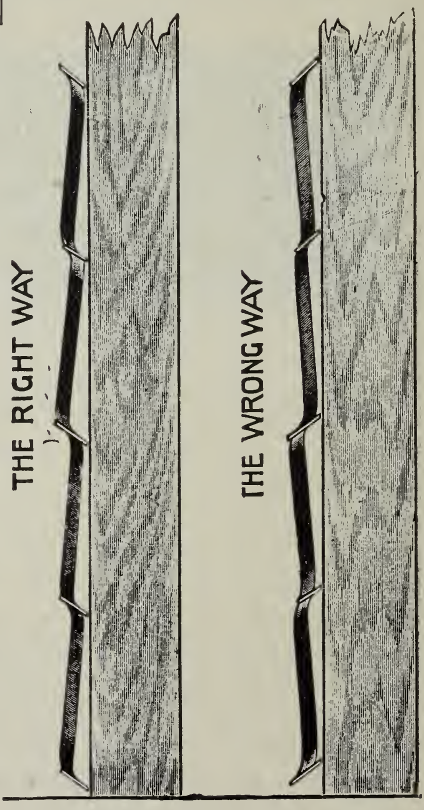


Fig. 431. Herringbone Lath. Manner of Applying.

There are some six or more styles of metal lath made from sheet-iron or steel by perforating the sheets so as to give a clinch to the mortar. The sheets are generally corrugated or ribbed, also, in order to stiffen them and keep them away from the wood. There is not a great difference between the different styles of these laths, although some may possess certain advantages over the others.

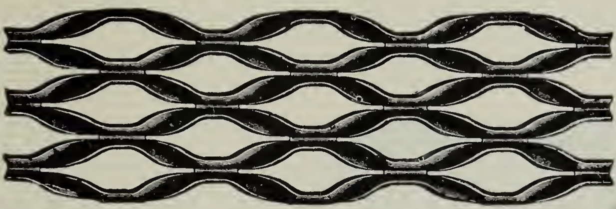


Fig. 432. Imperial Lath.

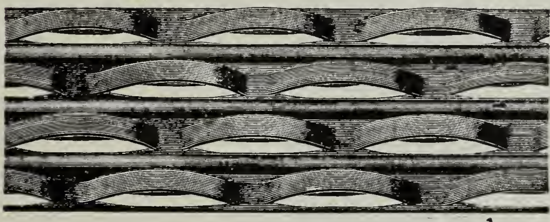


Fig. 433. Bostwick Lath.

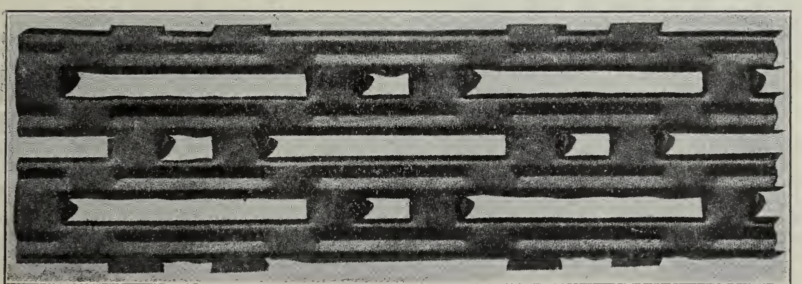


Fig. 434. Kühne's Clincher Lath.

In general those styles which have the greatest amount of perforations, or which approach the nearest to the expanded lath, are to be preferred. All of these laths come in flat sheets about 8 feet long, and from 15 to 24 inches wide, and are readily applied to

woodwork by means of barbed-wire nails. The nails should be driven every 3 inches in each bearing, beginning in the middle of the sheet and working toward the ends. These laths work very nicely in forming round corners and coves. Metal lath should never be cut at the angles of a room, but bent to the shape of each angle and continued to the next stud beyond. This strengthens the wall and prevents cracks at the angles.

Of the various forms of sheet-metal lath in common use the *"Bostwick" lath,* made by the Bostwick Steel Lath Company, of Niles, Ohio, shown in Fig. 433, is perhaps the best known. It is made of sheet-steel, with ribs every ¾ of an inch in the width of the sheet and loops, ⅜ by 1¾ inches, punched out between the ribs. It has been extensively used, and is favored by plasterers because it is stiff and easy to apply and requires less plaster than other metal laths which are more open. The lath should be applied with the loop side out.

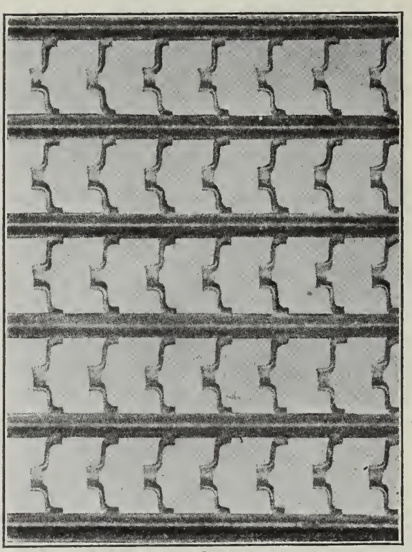


Fig. 435. Rib Lath.

Kühne's Clincher Lath is another form of patented perforated sheet-metal lath. It is manufactured and sold by the Truss Metal Lath Company of New York, in bundles of 9 sheets each, containing 16 square yards. The size of the sheets is 24 by 96 inches, and they may be obtained black, painted or galvanized. It makes a rigid lath formation, and the number and shape of the openings allow a good clinch for the plaster. Fig. 434 shows the form of this lath.

Rib Lath, made by the Trussed Concrete Steel Company of Detroit, Mich., and shown in Fig. 435, is sold in sheets 22 by 96 inches, 11 sheets and 18 square yards to a bundle, weighing for ordinary metal lath gauges 27, 26, 25 and 24, respectively 2.56, 3.19, 3.51 and 3.83 pounds per yard. For painting ½ cent per

square yard and for galvanizing 6 cents per square yard must be added to the price for the plain lath.

483. 4. OTHER FORMS OF METAL LATH.—There are *other good forms* of metal variously treated, already mentioned in connection with reinforcements for fire-proof floors, which can be used as lath for plastered partitions, when properly prepared in regard to size of mesh, etc., for that purpose.

Such are the *"Welded Fabric or Mesh,"* the *"Lock-woven Fabric,"* the *"Steel Wire Fabric"* of triangular and square mesh, already referred to, and other miscellaneous forms.

8. FIRE-PROOF FURRING CONSTRUCTION.

484. GENERAL CONSIDERATIONS.—Furring in general may be classified under two heads: First, the furring of constructive parts for purposes of protection against fire, dampness, etc., and, secondly, the furring of different parts for purposes of architectural form, sham construction, interior decoration, etc.

The first class may again be subdivided into two varieties, the furring of columns, girders, beams and other constructive metal, which variety has already been considered; and the furring of outside walls.

Although it is customary to plaster directly on the outside walls of fire-proof buildings, it is necessary below grade and often desirable above grade to fur the walls so as to leave an air-space, in order to prevent the passage of dampness. The furring material used is terra-cotta, hollow brick or some form of metal.

485. TERRA-COTTA AND HOLLOW BRICK WALL FURRING.—A common shape of furring tile is that shown in Fig. 436, the blocks being 12 inches square and 2 inches thick, although furring tile are made also 1½ inches thick, and in both larger and smaller sizes. They are made of dense, semi-porous and porous terra-cotta. With the latter no nailing strips are required, but it is better in any case to build in solid porous terra-cotta blocks whenever nailings are required for bases, wainscotings, picture-moldings, etc. It is doubtful if the porous materials offer as good protection from moisture as the harder burned tiles.

The ribs being set against the wall, an air-space is formed which checks the passage of moisture. The blocks should be set with the ribs vertical and fastened to the wall either by driving flat-headed nails into the joints of the brickwork, the heads of the nails

being bent down upon the tiles, or by using tenpenny nails and bending down their heads upon the blocks, one nail being used over every third block in every second course. The blocks should not be bedded in mortar at the back, since this would defeat their purpose by making solid connections to carry the moisture through.

Where walls must be straightened or furred out to a line with the face of piers, the 2-inch blocks cannot be used. If the ceiling height is not too great, 3-inch partition blocks should be used. If the space is greater than 3 inches, the blocks may be set out from the wall, leaving a clear air-space behind them. They should be braced at intervals by the use of drive-anchors. Four-inch blocks can be used without the anchors.

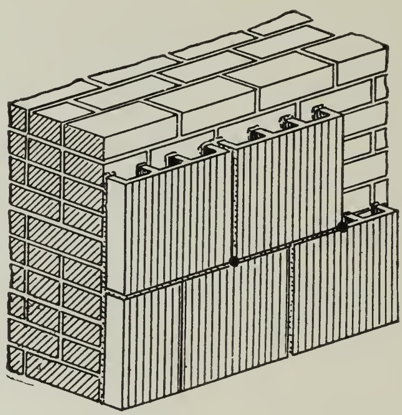


Fig. 436. Furring Tile. Common Shape.

The face of the blocks is grooved so that the plastering is applied directly upon them.

Hollow furring bricks, made of brick clay and of the same dimensions as common bricks, are very generally used for wall furring. Their cost is not a great deal more than that of common bricks, and they form the cheapest kind of furring with the clay products. They are built up with the rest of the wall and bonded into it with the usual header courses. Solid porous stretchers are made for insertion to hold the trim and other woodwork by nailing directly into them. Fig. 438 shows the hollow brick wall furring.

Fig. 437 shows a good method of furring the walls of rooms used for cold-storage, etc.

486. METAL WALL FURRING.—Various forms of metal

furring strips in connection with metal lath and plaster are used to fur the outside walls of fire-proof buildings and to obtain an air-space between the wall and the plaster, thus greatly diminishing the passing of moisture and of heat and the tendency to warp during a fire.

Fig. 439 shows the Roebling 1-inch "V-rib" metal furring with

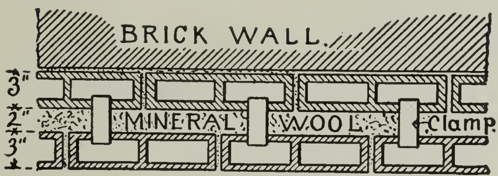


Fig. 437. Wall Furring for Cold-storage Rooms.

wire lath and plaster, and ¾-inch air-space. The V-ribs are woven in every 7½ inches.

Fig. 440 shows the Standard Concrete Steel Company's "Channel-block" furring.

Fig. 441 shows outside brick wall furred with the "Rib-lath Tri-

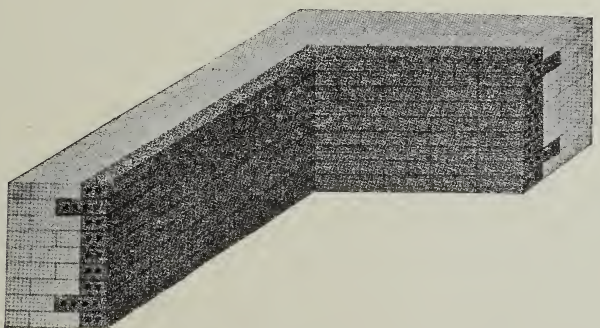


Fig. 438. Hollow Brick Wall Furring.

angular Expanded Furring Studs," made by the Trussed Concrete Steel Company.

Fig. 442 shows the "Allunited Steel Side-slot Furring Studs," made by the General Fire-proofing Company.

Fig. 443 shows the Prong Lock Wireless Steel Furring, made by the Berger Manufacturing Company.

Fig. 444 shows outside wall furring with angle or flat steel furring strips and metal lath, suggested by the White Fire-proof Con-

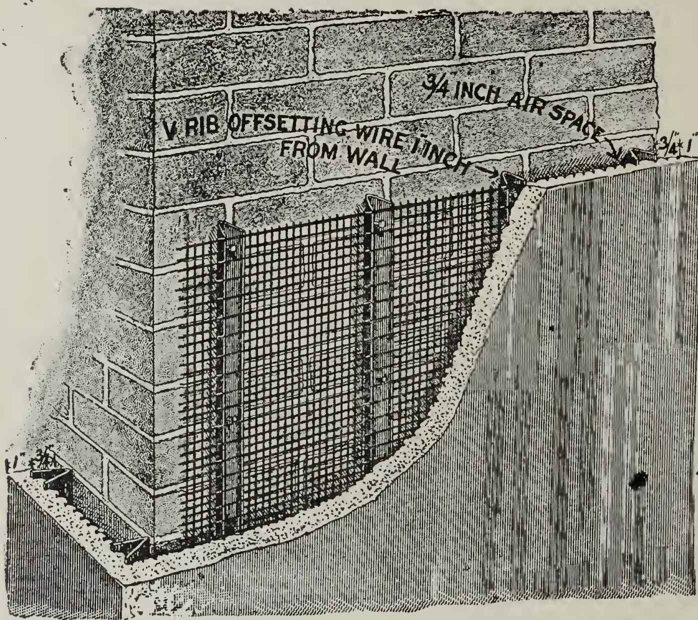


Fig. 439. Roebling Wall Furring.

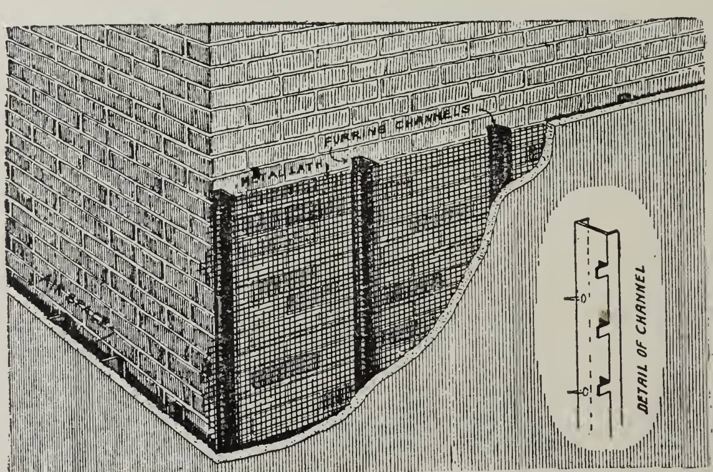


Fig. 440. Standard Wall Furring.

struction Company. The illustration shows the metal lath wall furring brought out to cover a duct and pipes.

487. FURRING FOR ARCHITECTURAL FORMS.—During the last few years metal furrings with metal lath have been

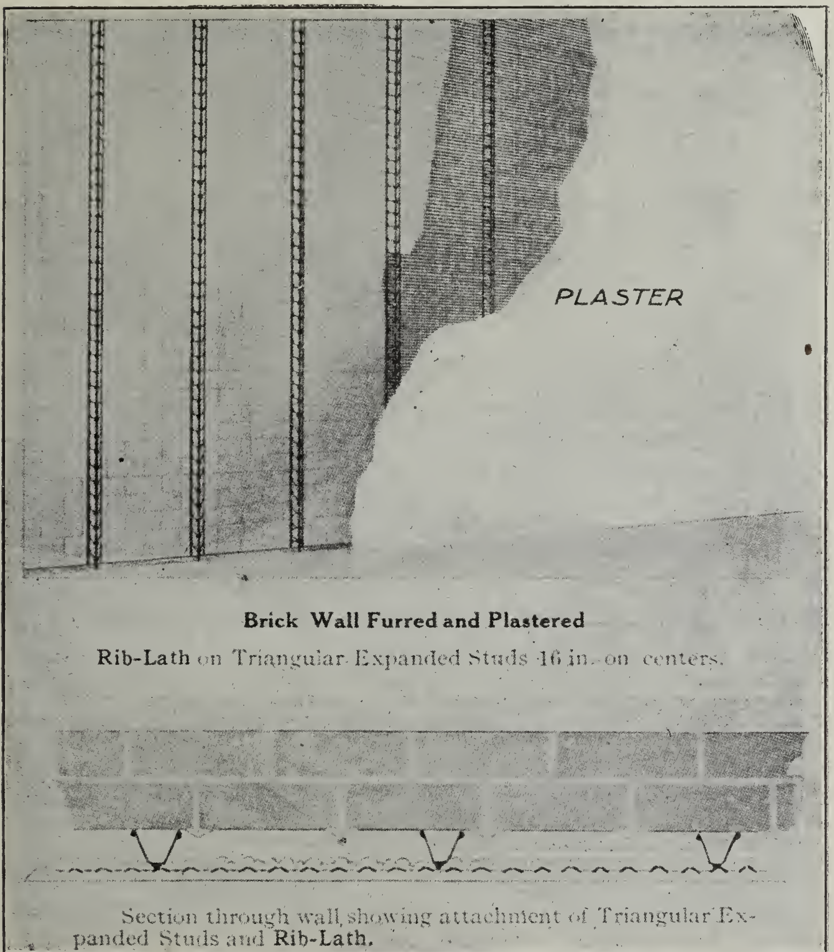


Fig. 441. Rib Lath Wall Furring.

largely used to obtain various architectural forms, such as coves, cornices, false beams, arches, vaulted ceilings, inner domes, etc., and to obtain different decorative effects.

This kind of furring is a sort of "false construction," the main

requirements of which are to furnish a firm groundwork for the metal lath and plaster and to be incombustible. It is not designed to carry weights of any magnitude.

The furring frame is fastened to the girders and beams by bolts and slips, and to the fire-proofing by staples, toggle-bolts, nails, etc. The general profile is formed by bending light irons, usually by hand, on a shaping plate, to the desired outline. These are secured in position, longitudinal rods fastened to their angles, and diagonal

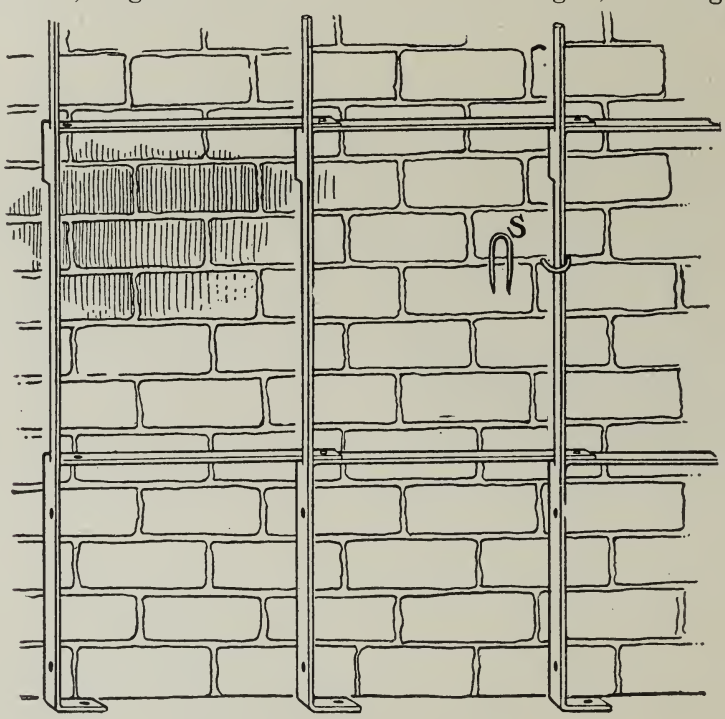


Fig. 442. Allunited Wall Furring.

bracing rods set for deep furrings, after which the metal lath is applied. Usually not more than from 1½ to 2 inches of plaster are required to give desired profiles, and not more than ¾ of an inch of plaster for plane surfaces. The spacing of the furring depends upon the kind of metal lath used, the usual spacing being 12 or 16 inches.

Metal furring and lath are used also for covering pipe casings, wall chases, etc., with fire-proofing material filled in solidly at each floor level to act as fire stops between stories.

Fig. 445 shows a method of furring and lathing for cornice profile, around a steel plate-girder dropped below the ceiling, ¼-inch rib-stiffened lath being applied to the furring or brackets which have been bent to the required outlines and set 16 inches on centers.

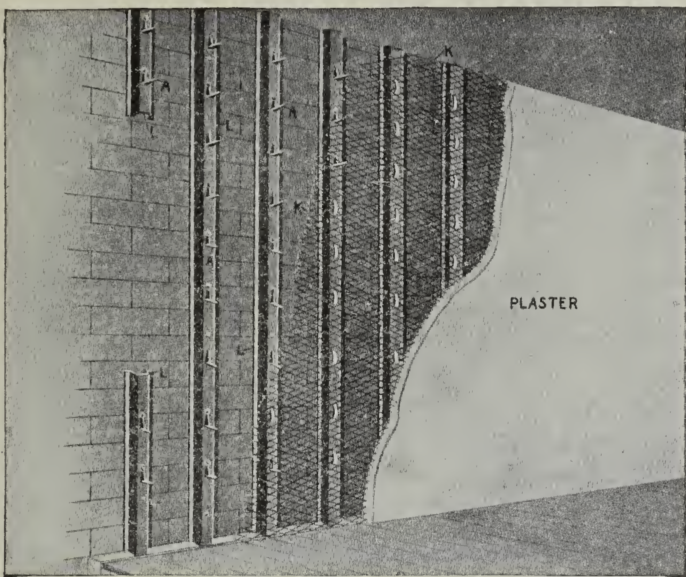


Fig. 443. Berger Prong-lock Furring.

Fig. 446 shows furring and lathing for ornamental false girder with cornice profile. In this case the bottom of the constructional girder is almost flush with the bottom of the floor beams.

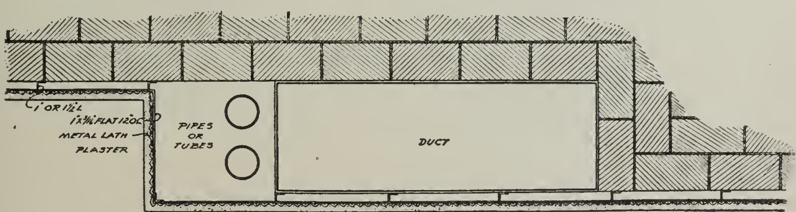


Fig. 444. White System of Furring Walls, Pipes and Ducts.

Fig. 447 shows furring for ornamental effects in plaster and electric lighting around constructional I-beam.

Fig. 448 shows furring for the foundation of a papier-mâché false ceiling beam, all hung from steel floor beam and ceiling.

Both wire lath and expanded-metal have been very extensively used for furring elaborate ceilings, beams, arches, vaults, etc., in public buildings; and wherever such furring has been removed or examined after a term of years, it has always, so far as known, been found to be in good condition and free from rust.

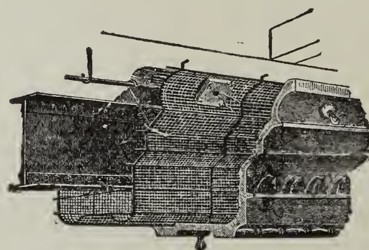


Fig. 445. Steel Beam Furring for Plaster Moldings.

The larger portion of the plaster beams, ceilings, domes, etc., of the Congressional Library are formed with expanded-metal on iron furrings, as were also the very elaborate ceiling of the dining-room in the Chicago Athletic Club and the domes and panelled ceilings of the New York Clearing House. In the main corridor of the Worthington Building in Chicago an elaborate vaulted mosaic ceil-

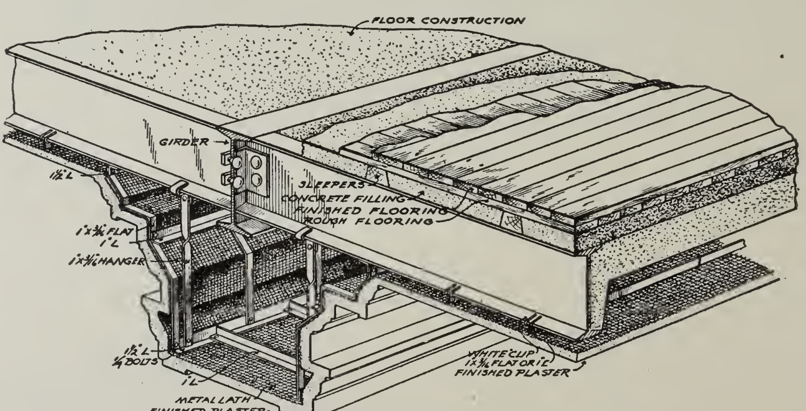


Fig. 446. Furring for False Girders.

ing is supported by a background of hard mortar on expanded-metal.

The extent to which both wire lath and expanded-metal may be used in forming a base for mortar and cement appears to be unlimited

When hollow tiles are used for fire-proofing, the grounds for the cornices are sometimes formed of terra-cotta, as shown in Fig. 449. Such grounds make a firmer base on which to carry the heavy

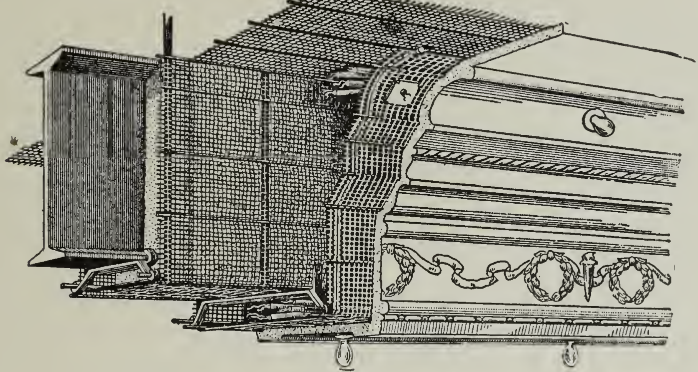


Fig. 447. Furring Steel Girder for Decorations.

stucco, and the plastering is not as liable to be broken by streams of water in case of fire. They are, therefore, often preferred to metal grounds, and have been largely used in the United States Government buildings where the ceilings have been of tile.

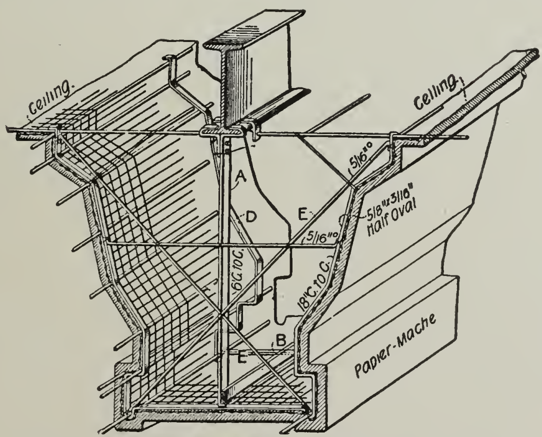


Fig. 448. Furring for Papier-mâché False Girder.

The various pieces forming the grounds should be bolted to the floor construction with ¼-inch T-head bolts spaced not over 12 inches apart longitudinally, and with at least two bolts to each piece.

These terra-cotta grounds have usually been made by manufac-

turers of flue-linings and pipes, as their machinery is better adapted to this purpose than that used for making fire-proof tiles.

9. FIRE-PROOF INTERIOR FINISH.

488. GENERAL DESCRIPTION.—Various incombustible materials are used for the interior finish in some important high buildings and also in some of ordinary height, with the object of making them more nearly fire-proof in all details. The materials used may be terra-cotta, cement, the incombustible compositions already mentioned as used for fire-proof floor coverings, metal or wood covered with metal.

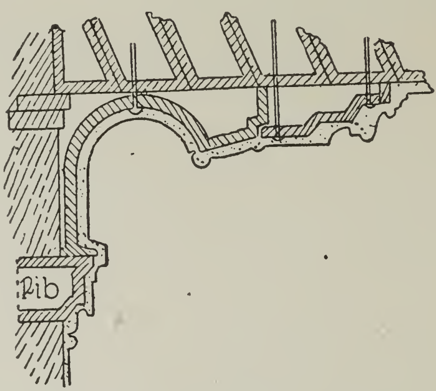


Fig. 449. Terra-cotta Cornice Grounds.

The last two do not belong to masons' work, and are simply referred to here.

Molded hollow *terra-cotta tiles* have been used as a substitute for wood inside finish, such details, for example, as door jambs and casings, baseboards and picture-moldings being made of specially formed tiles, built in place with the tile partition blocks left in sight and painted with the rest of the interior finish.

Very hard-setting special cements also, such as Keene's Cement, are used for the interior trim of fire-proof buildings. The moldings are run directly on the wall plaster or on the fire-proofing, often returning, as for example, on brick walls, to form the jambs. The cement may be painted, the angles may easily be made sharp and true, and the material is hard enough to stand any ordinary usage.

10. FIRE-PROOF STAIR CONSTRUCTION.

489. GENERAL DESCRIPTION.—The following is a general classification of the principal kinds of stairs constructed in fire-proof buildings:

1. Stone Stairs.
2. Brick Stairs, (1) with or (2) without slate or marble treads or risers.
3. Terra-cotta Hollow Block Stairs, each step in one piece.
4. Guastavino System of Flat Clay Tiles.
5. Metal Stairs, Cast-iron or Steel.
   (1) Without Slate or Marble Treads.
   (2) With Slate or Marble Treads.
6. Concrete Stairs.
   (1) Without Reinforcement.
      (*a*) Monolithic, with or without slate or marble treads or risers.
      (*b*) With steps cast separately and set in place.
   (2) With Reinforcement, with Construction Steel Stringers, or with Reinforced Concrete Stringers.
      (*a*) With wire or lath reinforcement.
      (*b*) With plates like "ferroinclave," "ferrolithic," etc., for treads and risers, plastered.
      (*c*) Without slate or marble treads and risers.
      (*d*) With slate or marble treads and risers.

1. *Stone* steps and stairs have already been referred to in Chapter VI, "Cut Stonework." Stone, however, from the point of view of fire-resistance, is not a good material for stair construction.

2. *Brick* stairs have been described in Chapter VII, "Bricks and Brickwork."

3. *Terra-cotta* hollow block stairs have been successfully built. In one building, the Amelia apartment-house, at Akron, Ohio, each step was one entire block of hard-burned, glazed terra-cotta, 4 feet long, 6½ inches high and 11 inches wide, not including the nosing and cove of the upper tread surface, the extreme width of the upper surface being 14 inches. The steps were made by forcing the clay through a die in the same manner as for fire-proof tiles. They were made with molded nosings and with smooth finish. The blocks were made with two vertical webs, were supported by the partition walls, and were found to be of ample strength. Another prominent example of terra-cotta hollow block stairs is in the model

fire-proof building erected for the Fire Insurance Underwriters' laboratory, in Chicago, according to the methods and with the materials of the National Fire-proofing Company.

4. The R. Guastavino Company have erected a number of staircases, using their *flat clay tiles* in cement without iron work of any kind, and with a resulting advanced type of fire-proof construction.

5. *Iron* and *steel,* while used more than any other incombustible material in staircase construction, cannot be classed with the fire-proof materials, when unprotected. Of the two exposed metals, the thin facing sheets of steel are inferior to those of cast-iron, as they warp in intense heat. It is desirable to do away with as much iron as possible in really fire-proof stair construction. Regarding slate and marble treads and platforms, it may be said that they should always have ample support under the middle parts as well as under the edges, as they crumble away from intense heat.

6. Since the introduction of reinforced concrete construction, many staircases have been built of *concrete* with variations in detail as briefly outlined in the foregoing classifications in this article. A good construction results from the use of marble or slate treads set on reinforced concrete, which usually consists of a wet, rich mixture with small aggregate for convenient casting into the desired shapes. The stairs of the new Government Printing Office at Washington are constructed of reinforced concrete steps and platforms, supported on the sides by steel girders and stringers which are enclosed in solid concrete. The reinforcement near the lower side of the sloping mass of concrete forming the staircase run is accomplished by the use of ½-inch bars, 7 inches on centers parallel with the treads and rises, and of ½-inch bars 2 feet on centers running up the string. Slate and marble are used for the treads and risers.

Fig. 450 shows the above-described type of reinforced concrete stairs.

Fig. 451 shows the details of the design of the reinforced concrete stairs in the Ketterlinus Lithographic Manufacturing Company's building, Philadelphia.*

Fig. 452 shows a section through the treads and risers of stairs constructed with the corrugated sheet-metal known as "Ferroinclave," in which the treads and risers made of these sheets are

* Designed by Ballinger & Perrot, architects and engineers, Philadelphia.

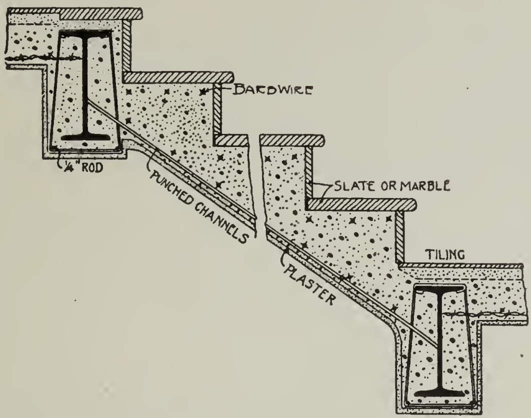


Fig. 450. Reinforced Concrete Stairs.

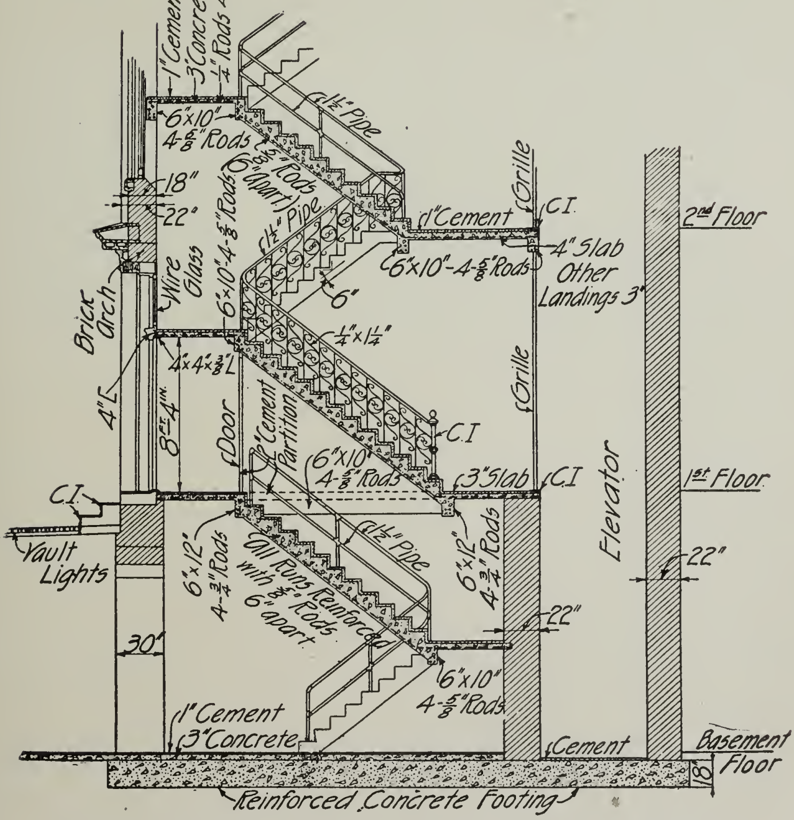


Fig. 451. Reinforced Concrete Stairs. Ketterlinus Building, Philadelphia.

either built between walls or partitions, or built with "open strings" of steel channels or I-beams, to which they are bolted by means of lugs or brackets screwed to or cast on the strings. About 2 inches of cement are put over the metal sheets and they are plastered on the under side, the treads and risers being frequently of slate or marble.

11. MISCELLANEOUS DEVICES IN FIRE-PROOF BUILDINGS.

490. GENERAL DESCRIPTION.—These additional devices will be simply enumerated here, as they do not come under the head of masons' work.

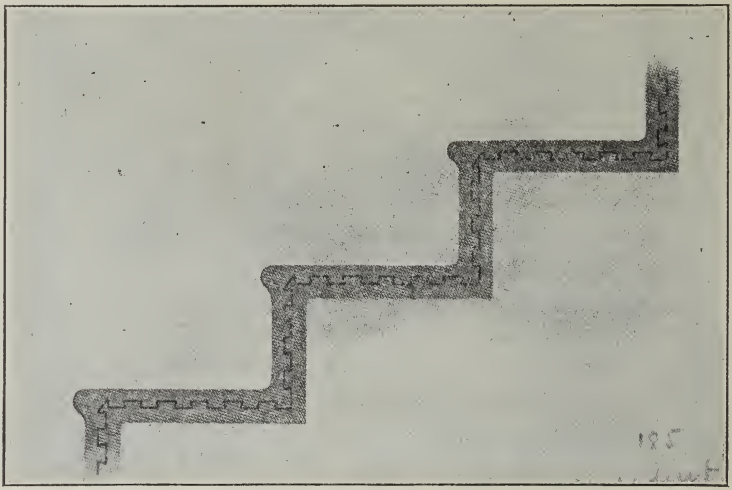


Fig. 452. Reinforced Concrete Stairs. Ferroinclave.

They may be classified as "protecting devices," "precautionary devices" and "devices for extinguishing fires."

To these additional devices belong the different types of window-protection, such as tin-covered wood shutters, steel shutters, metal frames and sashes, wire-glass, automatic alarms, water-curtains, automatic sprinklers, stand-pipes, hose-reels, etc.

For a description of these see Chapter XXIII, "Fire-Proofing of Buildings," in the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

12. FIRE-PROOF CONSTRUCTION FOR DWELLINGS AND OTHER BUILDINGS OF MODERATE SIZE.

491. GENERAL DESCRIPTION.—Under the general subject of fire-proofing, reference should be made to recent methods of fire-

proof construction used for dwellings especially and for other classes of buildings of moderate size and cost.

Besides the usual methods described in the foregoing pages, which pertain more particularly to buildings with outside brick bearing walls or with the skeleton frame and brick curtain-walls, there may be mentioned also the method employing *concrete,* solid or in the form of hollow blocks, or *hollow terra-cotta tile blocks* for the construction of the outside walls.

The concrete construction is considered in Chapter X.

492. TERRA-COTTA HOLLOW TILE OUTSIDE WALLS. —Fig. 453* shows the general constructional details of a dwelling

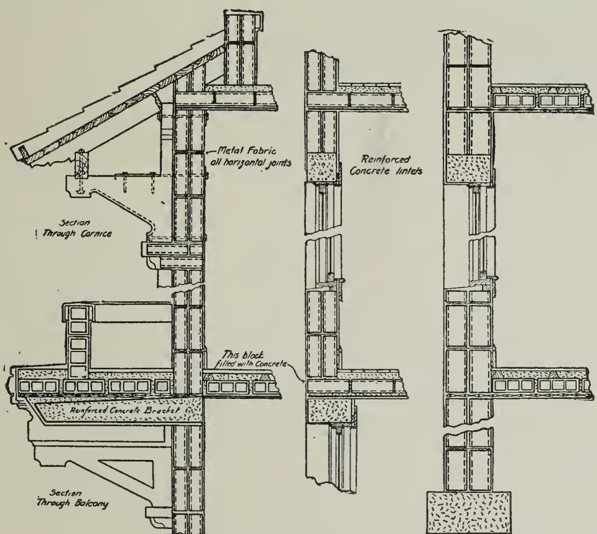


Fig. 453. Terra-cotta Hollow Tiles for Outside Walls.

in which these materials were used. The exterior walls are built of doubled 6-inch and doubled 4-inch hollow tiles, set with the ribs vertical, the partitions of 4-inch tiles and the floors and roof according to the "Johnson" floor system, 4-inch tiles being generally used.

The foundations are of concrete, and reinforced concrete is used for interior girders and exterior lintels. The spans of floors and roof range from 16 to 20 feet. The chimneys, balustrades and many other details are built of hollow tiles. The roof is flat, the

* Fire-proof residence of Mr. G. E. Bergstrom, architect, Los Angeles, California. Courtesy of the National Fire-proofing Company.

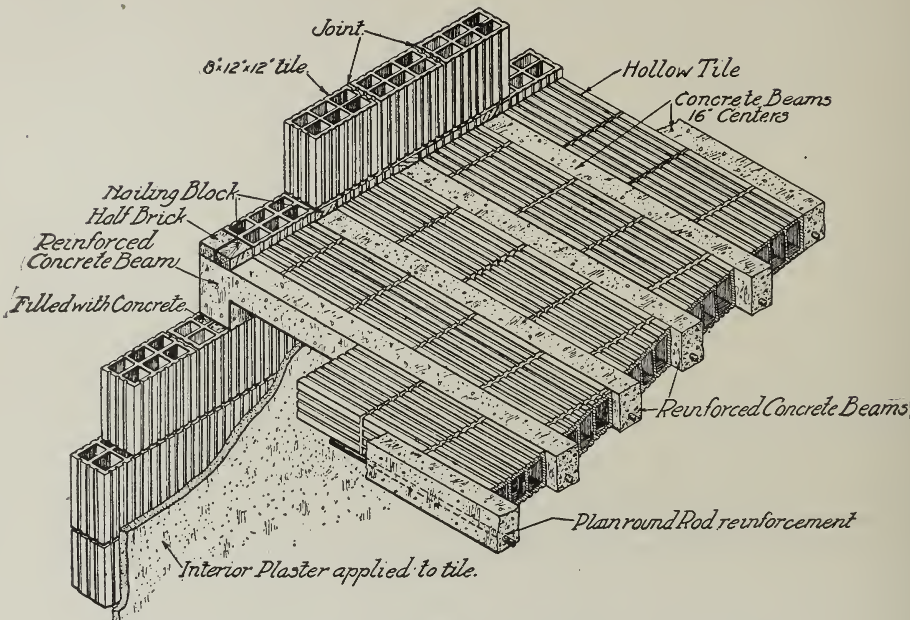


Fig. 454. Terra-cotta Outside Wall with Tile and Concrete Floors.

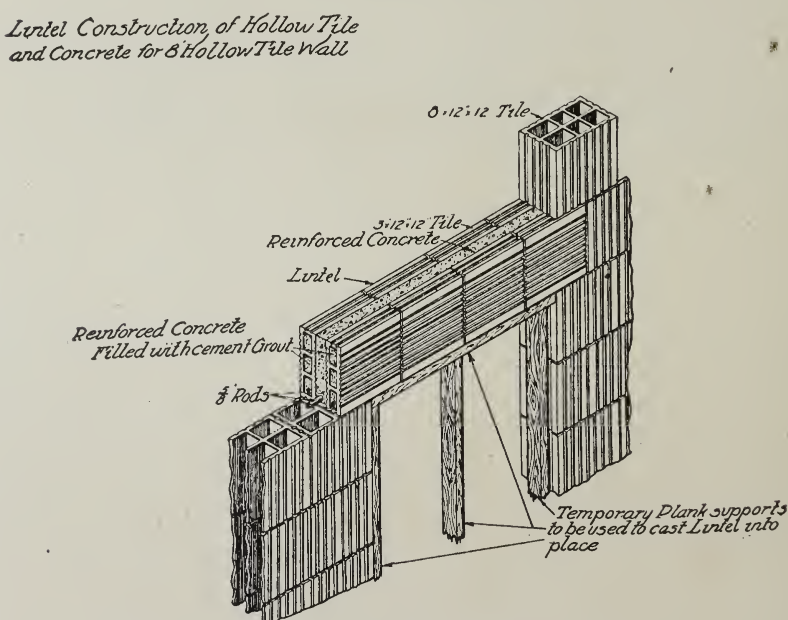


Fig. 455. Terra-cotta Outside Wall and Lintel Construction.

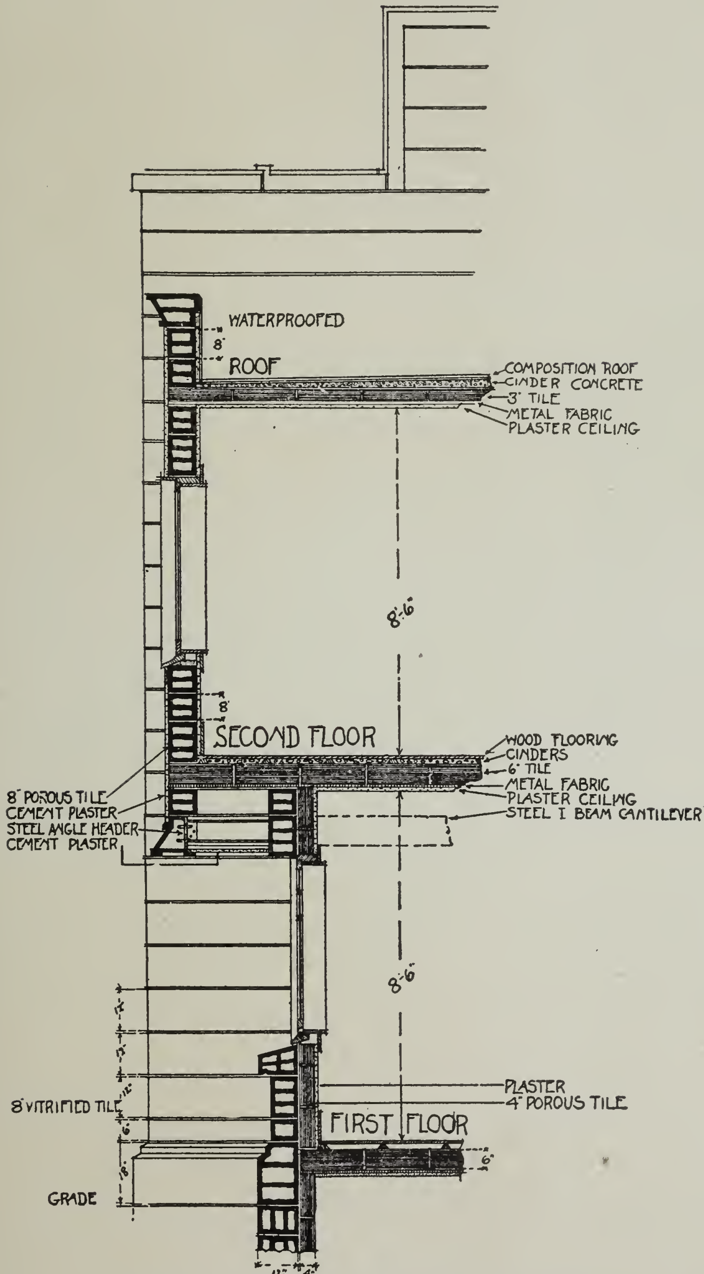


Fig. 456. Terra-cotta Outside Wall Construction.

sloping eaves being covered with "Mission" tiles. No steel is used for construction except as a tension material. The entire exterior is coated with cement and fine gravel, and treated with acid to remove the cement from the exposed surface and to leave the gravel visible. The eaves are carried on wooden frames supported by and tied to the cornice brackets, as shown in the figure.

Fig. 454 shows details of another building with hollow tile outside walls and with hollow tile and reinforced concrete floor construction.

Fig. 455 shows details of hollow tile and reinforced concrete lintel construction over an opening in 8-inch hollow tile walls.

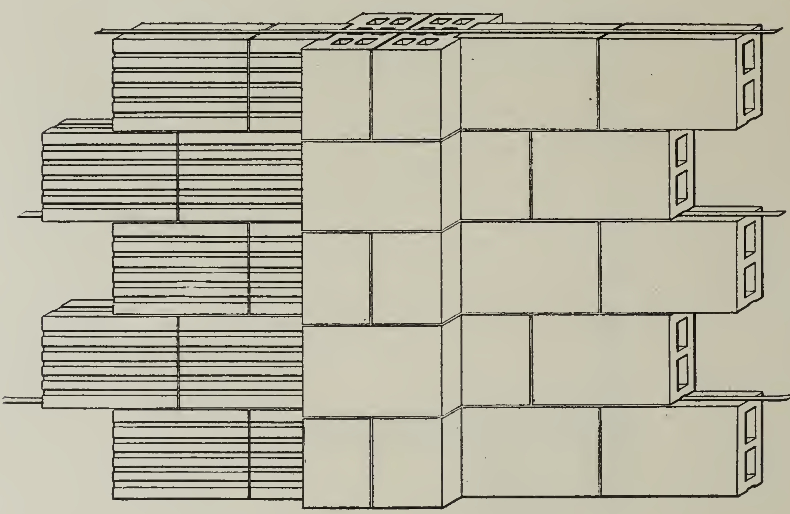


Fig. 457. Terra-cotta Phœnix Outside Wall.

Fig. 456* shows vertical section of fire-proof dwelling, indicating the terra-cotta materials and construction.

Fig. 457 shows the general method of constructing the "Phœnix" outside wall of hard-burned hollow clay blocks, with grooves in them at tops and bottoms to receive the courses of band-iron horizontally and continuously. These blocks are made by Henry Maurer & Son, New York, and come in various convenient sizes, usually 8 by 12 inches in height and length, and in 4-, 6-, 8 and 12-inch thicknesses. The illustration shows the wall with a pier, and with smooth surfaces and also with ribbed surfaces for plastering.

* See "Fire-proof Residences," by Charles E. White, Jr., architect, Chicago, published by the National Fire-proofing Company. Drawing reproduced by permission.

13. EARTHQUAKE-RESISTING CONSTRUCTION IN FIRE-PROOF BUILDINGS.

493. GENERAL DESCRIPTION.—Fig. 458 shows the general system of construction designed to resist the destructive effects of earthquakes, and patented by Mr. Peter H. Jackson, of San Francisco, California.

The figure is a perspective view of a solid front wall and a return wall having a window opening, both walls being between steel

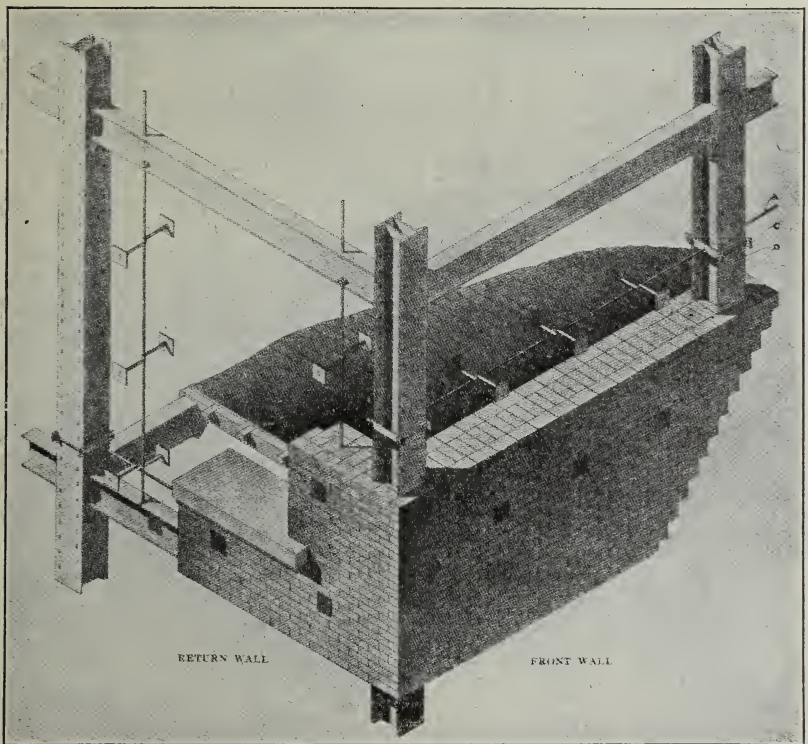


Fig. 458. Jackson Earthquake-proof Construction.

columns and enclosing them. Tie-rods ¾ of an inch in diameter extend as shown *horizontally* along the middle thickness of the front wall with their ends fastened to the columns. In the return wall two rods are shown extending *vertically* with their ends fastened to the top and bottom cross I-beams. These vertical rods, with the anchors, are so placed as to hold and stiffen the edges of the wall forming the window or door opening, while a horizontal tie-rod is

shown extending across the wall at the bottom of the opening beneath the window sill. *These tie-rods have to be adjusted in places to meet the requirements of every case.* Clamps are shown on the two front columns to which the ends of the tie-rods are secured; but they may be used in the same way when fastened on the cross beams. They are inexpensive, and in many cases have to be used in order that the tie-rods may extend through, as near the middle thickness of the wall as possible, as shown in Figs. 459 and 460. The manner of fastening the clamps to the columns is illustrated in these figures. The tie-rods are fastened to the plates G and the bolts D hold the plates to the column.

The cross-anchor portion that extends through the wall is usually made of 1-inch by ¼-inch flat iron. Its flat part is shaped by bend-

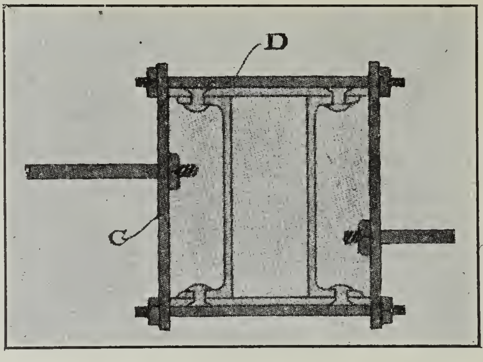


Fig. 459. Jackson Construction. Column Clamp.

ing it round an iron rod and the end plates are attached as shown in Fig. 461. These anchors are strung on the horizontal tie-rods, as shown in the front wall, or strung on the vertical tie-rods at the side of the window opening, as shown in the return wall, Fig. 458.

Fig. 462 shows a cross-section of a brick or concrete wall with the tie-rod in its middle and a cross-anchor strung on the rod. Fig. 463 shows another view of wall and anchors, the tie having three cross-anchors extending vertically through the middle of the wall. The end plates of the anchors are shown extending their thickness outside of the wall; but for a face-brick wall the outside plate of the anchor is just flush with the face of wall and the width of two face-bricks, with a countersunk hole in the middle of its height, the tenon of crosspiece being rivetted flush with the face of the plate, so that the latter is not distinguished from the other face-bricks of

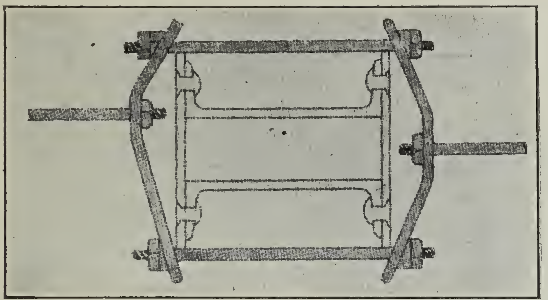


Fig. 460. Jackson Construction. Column Clamp.

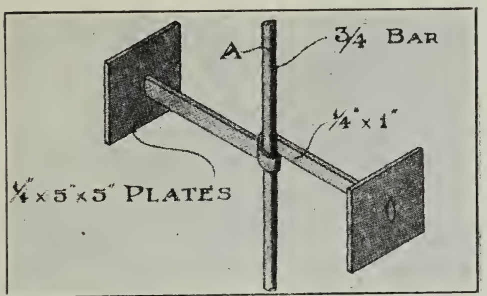


Fig. 461. Jackson Construction. Wall Anchor.

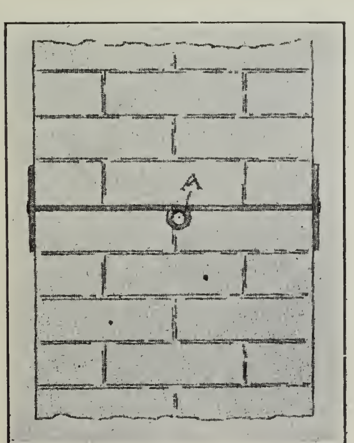


Fig. 462. Jackson Construction. Wall Construction.

the wall. The inside plate is on the inside face of the wall. The front plates of these anchors for a face-brick wall are galvanized and then well painted to avoid discoloration by rust.

The clamping pieces, Figs. 459 and 464, admit of the tie-rods being placed at any distance up or down on the columns and to the right or left of the cross beams.

14. PELTON'S SYSTEM OF RELEASED WALL FACING.

494. GENERAL DESCRIPTION.—During the years, from 1892 to 1896, Mr. John Cotter Pelton, architect, developed and patented a system of released wall facing which met with commendation from many architects, and which

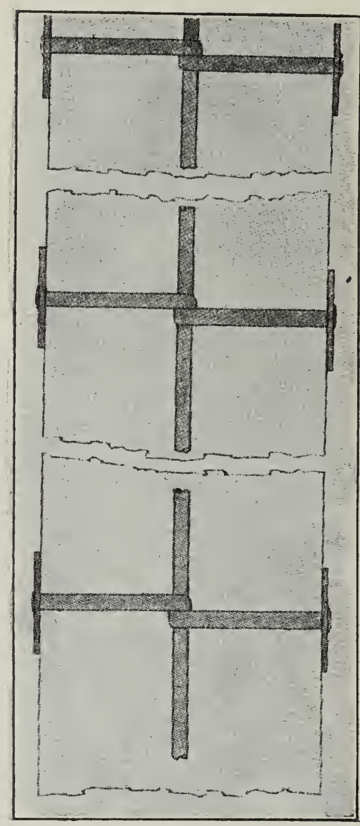


Fig. 463. Jackson Construction. Wall Construction.

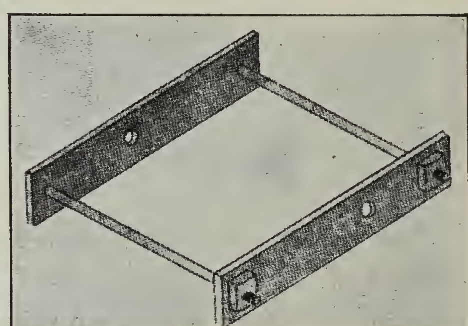


Fig. 464. Jackson Construction. Clamping Piece.

the author believes to be sufficiently practicable to interest all architects and students. The essential feature of this invention is the idea of supporting a costly facing of stone, marble or terra-cotta from a wall of common masonry, or from a steel frame, by means of metal anchors and brackets, which hold the facing away from the wall or frame and also permit of its being set after the supporting wall is completed. The general principle of construction is quite clearly indicated by Fig. 465.

The five advantages claimed for this system are: First, economy

of material in the facing; secondly, saving in time required to complete the building ready for occupancy; thirdly, protection against the penetration of moisture; fourthly, elimination of the bad effects of settlement in the walls and the loosening of the facing from the backing; fifthly, protection against exterior fire. Of these advantages the first and second will probably have the most influence in extending the use of the system, as they have a direct bearing upon the cost and financial returns of the building. The other advantages,

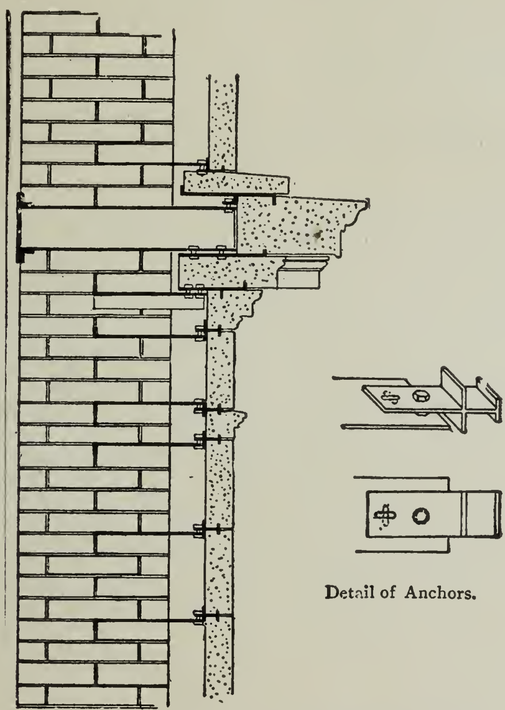


Fig. 465. Pelton System of Released Wall Facing.

however, are perhaps the most important from a constructive standpoint.

As the facing is treated merely as an external covering, principally for architectural effect, and has nothing to support, it can be made very thin, thus permitting the use of expensive materials, which, with the ordinary method of construction, would be prohibited on account of the cost.

The anchors which support the facing being built into the sup-

porting wall as it progresses, the facing can be applied after the roof is on and while the building is being finished on the inside, or even after the building is occupied. Hence a building faced with marble under this system could be completed ready for occupancy in about the same time that would be required if the walls were of plain brickwork, ample time being allowed for cutting and setting the facing, and even for quarrying the stone. In fact, any unavoidable delays with the stonework, such as strikes, unfavorable weather, etc., need not delay the finishing of the interior of the building.

As a protection from dampness the advantage of this system is obvious, as a continuous air-space is provided between the facing and the supporting wall, with only the metal anchors connecting the two.

The facing being applied after the supporting wall is completed, all settlement in the latter will have taken place before the ornamental work is set, thus avoiding the cracks which frequently occur in facings that are bonded into a brick backing. Of course any settlement in the foundations would affect the facing as well as the supporting wall. A facing supported in this way will serve also, while it endures, to protect the supporting wall from external fires; and should a portion or all of the facing be injured beyond repair, it can be removed and new pieces substituted. A facing of either marble or limestone would probably protect the structural wall from serious damage from any ordinary fire; and even when the fire is inside the building this method of facing is likely to prove an advantage. In such cases the flames generally destroy the stonework around the exterior doors and windows, and with a released facing injured stones can be replaced if the structural wall is not weakened.

This system of construction was adopted in a few buildings in California, of which the Public Library at Stockton, a building in the Renaissance style and designed by Mr. Pelton, is one of the most elaborate.

This building stands on a corner and has exposed about 210 feet of frontage, the whole of which is of white marble on a light gray granite foundation wall 7 feet high. The structural walls are of brick, 24 inches in thickness, and the ashlar is 2¼ inches thick, with an air-space of 2¾ inches. The whole of the work on this building, except the finishing coat of plaster and the interior woodwork, was

completed before the marble for the façade was delivered upon the ground. The whole cost of the exterior marble work was less than $17,000, in which is included not less than $3,000 for carving and the cost of six monolithic columns 16 feet in height.

The anchors or carriers in this building were all set and adjusted by an engineer, so as to secure perfect alignment, and no difficulty appears to have been encountered in any portion of the work, the appearance of the building on completion being the same as if constructed in the ordinary way.

At one time during the progress of the work there were men at work at not less than five different parts of the building and on eight different levels.

Every stone sent to the staging as correct in size was set without trimming; in fact, fitting and trimming were not known upon the staging. The only cutting known to have been done in the work of setting was the small amount of channelling required for the carriers, and this work hardly occupied the time of one workman.

The shape and size of the carriers or anchors will necessarily depend a good deal upon the size and weight of the pieces to be supported. The shape of some of the carriers used in the Stockton Library is shown in Fig. 465. To insure the successful setting of the facing the carriers must be set with great exactness, and Mr. Pelton recommends that an engineer be employed to give both the horizontal and plumb lines.

The window frames should be set before the facing and the latter built around them.

As stated in the first paragraph, this system of construction was patented by Mr. Pelton.

Chapter X.

Concrete and Reinforced Concrete Construction.

I. CONCRETES.

495. DEFINITIONS.—*Concrete* is really an artificial stone. It is made by mixing cement, or some similar material, with sand and with different-sized pieces of broken stone, gravel, cinders, slag, coke, broken bricks, or other coarse stuff of like nature.

The Matrix.—The active element of the concrete is the cement, which is sometimes called the "matrix."

The Aggregate.—The inert elements of the concrete are the sand, broken stone, etc., which are called the "aggregate."

Rubble Concrete is concrete in which large stones are placed.

Bituminous Concrete.—Asphalt, coal-tar and pitch are used with sand to make bituminous mortar and concrete. It is used in roadway pavements and in foundations for machinery when vibration is to be avoided.

Reinforced Concrete is a compound or heterogeneous material, composed of a metal skeleton work imbedded in a mass of concrete or cement mortar. Other names for it are "ferro-concrete" and "armored concrete." It is plain concrete to which is given the requisite strength in tension and sometimes also in compression by the imbedding of steel or wrought-iron rods, and which also has its resistances to lonigtudinal and shearing stresses assisted by these same or similar rods.

496. EARLY USE OF CONCRETE.—Concrete has been used from very early times by the Egyptians and the Romans, and it was probably known to the ancient inhabitants of Mexico and Peru and other countries. It was used by the Romans in aqueducts, sewers, water-mains, foundations, buildings, roads, etc., and possessed such strength and toughness that many relics of works in which it was used still remain.

497. PRESENT USES OF CONCRETE.—The use of concrete

is increasing every year, and it may be considered one of the most valuable of the building materials. It is especially useful in the following kinds of construction: Heavy foundation work; underground subways and tunnels; foundations of engines or machinery; walls and foundations of heavy walls or piers; sidewalks or floors; constructions in which the stresses are chiefly compressive, such as arches, dams, retaining-walls, penstocks, bridges, abutments, sewer and water conduits, reservoirs; foundations for roadway pavements; fortification work, on account of its resistance to the penetration of large projectiles; submarine work, where it may be laid when necessary without excluding the water; breakwaters, dikes and wharves; concrete building blocks, etc.

It is also well adapted to the construction of vats or tanks holding liquids which have a destructive action upon iron or wood.

When concrete is properly reinforced the variety of its uses is almost endless. It then becomes adapted to beam and column construction, to floor and roof arches, chimneys, standpipes, piles, railroad ties, fence posts, thin walls, bridge floors, and to many other kinds of construction mentioned in the foregoing paragraphs of this article.

It is quite possible also to cast concrete in molds in a manner similar to that in which plaster of Paris is run, and there have been many recent attempts to treat concrete surfaces decoratively, which have met with considerable success. (See also Article 525, "Uses of Reinforced Concrete Construction.")

498. SELECTION OF MATERIALS.—The ordinary composition of concrete is a mixture of cement, sand, gravel or crushed stone, or gravel and crushed stone together, and water.

It is better to use Portland cement for concrete for nearly all classes of work, as it has generally greater uniformity and greater strength, and consequently yields better results than do natural cements at the same or lower cost, when mixed with larger proportions of sand and stone.

The sand is better when clean and composed of a mixture of coarse and fine grains.

Broken stone or gravel, or both together, may be used. If the gravel is clayey or dirty it should be washed before mixing. If broken stone is selected, it is usual to limit the maximum size to 2½ inches. Smaller maximum sizes are sometimes used to give

finer surfaces. Graded stone, such as "crusher run," or gravel from ¼ to 2 inches in size give the best results.

499. PROPORTIONS OF MATERIALS.—The following four proportions for different mixtures are given by Taylor & Thompson* as a guide to the selection of materials for various classes of work, and differing from each other simply in the relative quantity of cement. They are based upon fair average practice:

"*A Rich Mixture.*—For reinforced engine or machine foundations subject to vibrations, for reinforced floors, beams and columns for heavy loading, for tanks and other water-tight work. Proportions 1:2:4; that is, 1 barrel (4 bags), packed Portland cement (as it comes from the manufacturer), to 2 barrels (7.6 cubic feet), loose sand, to 4 barrels (15.2 cubic feet), loose gravel or broken stone.

"*A Medium Mixture.*—For ordinary machine foundations, thin foundation walls, building walls, arches, ordinary floors, sidewalks and sewers. Proportions 1:2½:5; that is, 1 barrel (4 bags), packed Portland cement, to 2½ barrels (9.5 cubic feet), loose sand, to 5 barrels (19 cubic feet), loose gravel or broken stone.

"*An Ordinary Mixture.*—For heavy walls, retaining walls, piers and abutments, which are to be subjected to considerable stress. Proportions 1:3:6; that is, 1 barrel (4 bags), packed Portland cement, to 3 barrels (11.4 cubic feet), loose sand, to 6 barrels (22.8 cubic feet), loose gravel or broken stone.

"*A Lean Mixture.*—For unimportant work in masses where the concrete is subjected to plain compressive stress, as in large foundations supporting a stationary load or in backing for stone masonry. Proportions 1:4:8; that is, 1 barrel (4 bags), packed Portland cement, to 4 barrels (15.2 cubic feet), loose sand, to 8 barrels (30.4 cubic feet), loose gravel or broken stone."

TABLE XXX.

Materials for One Cubic Yard of Portland Cement Concrete.

Proportions.	Cement. Barrels.	Sand. Cubic Yards.	Gravel or Stone. Cubic Yards.
1:2:4	1.57	0.44	0.88
1:2½:5	1.29	0.45	0.91
1:3:6	1.10	0.46	0.93
1:4:8	0.85	0.48	0.96

500. QUANTITIES OF MATERIALS.—The above table

* "Concrete, Plain and Reinforced." Taylor & Thompson.

is made from the formulas devised by William B. Fuller for determining the quantities of materials for one cubic yard of Portland cement concrete of different proportions of cement, sand and gravel or stone. (See Article 499, Proportions of Materials for these same mixtures.)

In the table, and in the proportions, a barrel of Portland cement is taken at 376 pounds, equal to 4 bags and as "packed;" a barrel of loose sand is taken equal to 3.8 cubic feet; and a barrel of loose gravel or stone at 3.8 cubic feet.

501. MIXING THE CONCRETE.—Concrete may be made either by machine-mixing or by hand. The quantity to be laid and the relative cost of the two methods determine the advisability of employing one or the other method, and the relative cost depends upon circumstances and has to be estimated for each individual case.

Mixing by Machinery.—On large contracts machinery is universally replacing hand labor. Concrete mixers may be classified under two general heads: (1) continuous mixers, into which the materials are constantly fed, generally by shovelfuls, the concrete discharging in a steady stream, and (2) batch mixers, which receive in one charge a certain large amount, such as a barrel of cement or a bag of cement and the accompanying proportionate volume of sand and stone, and which, after the mixing, discharge the cement in one mass.

Again, concrete mixers may be classified into three general types: (1) rotating mixers, (2) paddle mixers and (3) gravity mixers, all depending upon the manner in which the mixing process is accomplished.

Mixing by Hand.—The most satisfactory method of mixing concrete by hand is to first prepare a tight floor of plank, or better still, of sheet-iron with the edges turned up about 2 inches, to hold the mixture.

Upon this platform the sand should be spread first; and the cement should be spread over the sand. The two should then be thoroughly and immediately mixed by means of shovels or hoes, the broken stone or aggregate then dumped on top and the whole worked over with shovels first, while dry and afterward, a second time, while water is added from a sprinkler on the end of a hose. After enough water has been added, the mass should be again worked over at least twice. For a moderately dry mixture only as much

water is added as is necessary to enable the mortar to completely coat and cause to adhere all the particles of the aggregate, so that when the concrete is tamped the water will just flush to the surface without much quaking. (See also Article 502.)

The water used should be clean and at about the temperature of 65° Fahr.

502. PLACING OR DEPOSITING CONCRETE.—Concrete is usually deposited in layers from 6 to 10 inches thick, and should be carefully put in place so that the materials will not separate. It may be wheeled in barrows immediately after mixing, and gently tipped or slid into position and at once rammed before the cement begins to set, the ramming or tamping being continued until the water begins to ooze out upon the surface. Square wooden rammers measuring from 6 to 8 inches on a side, or round ones from 8 to 12 inches in diameter and weighing between 10 and 20 pounds, are generally used. In a dry or jelly-like mixture the mass should be rammed until the mortar flushes to the surface, while for a wet concrete the mass should be merely puddled or "joggled" to expel the air and the surplus water. (See also Article 501.)

Whenever possible, sections of concrete work should be carried on continuously until completed, in order to avoid lines of cleavage; but when the depositing must be done in layers, before beginning the work anew, the surfaces should be cleaned, roughened and wet, or washed with a neat cement paste or grout having the consistency of cream. It is now recognized that for the strongest construction and for water-tight work, concrete should be as nearly as possible one single solid mass with no joints; and to accomplish this result the concrete is made to have a "quaking," jelly-like consistency, or even made with enough water to be "mushy" or "sloppy."

503. THE STRENGTH OF CONCRETE.—The following conditions determine the strength of concrete: (1) the quality of the materials, (2) the quantity of cement in a cubic yard of the concrete and (3) the density of the mixture.

The average ultimate *crushing strength* of natural cement concrete of the usual average materials, one year old, is about 800 pounds per square inch; that of a 1 to 2 to 4 Portland cement concrete is from 2,000 to 2,200 pounds per square inch and that of a 1 to 3 to 6 Portland cement concrete is from 1,600 to 1,800 pounds

per square inch. These are average values for reasonably good conditions as to character of materials and workmanship.

The *tensile strength* of concrete is very much less than the compressive strength, but it cannot be accurately given. When the concrete is made with care it is probably safe to say that its strength per square inch will be from one-tenth to one-eighth of its compressive strength, although there is no fixed relation between the two values.

TABLE XXXI.

Compressive and Tensile Strength of Portland Cement Concretes Compared.

Tests by Professor W. K. Hatt gave the following results:

Kind of Concrete.	Age, days.	Comp. Strength, lbs. per sq. in.	Tens. Strength, lbs. per sq. in.
1:2:4 (broken stone)	30	——	311
1:2:5 (broken stone)	90	2413	359
1:2:5 (broken stone)	28	2290	237
1:5 (gravel)	90	2804	290
1:5 (gravel)	28	2400	253

Regarding the ultimate flexural fiber stress or *modulus of rupture,* for Portland cement concrete, it is from one and one-half times to twice the ultimate direct tensile stress, or from one-seventh to one-fifth the direct crushing strength.

Using experimental crushing tests as a basis, the *safe working loads* for concrete may be assumed to range from one-third to one-tenth of the breaking loads, depending upon various conditions.

The following table gives the safe strength of Portland cement concrete in *direct compression,* based upon conservative practice:

TABLE XXXII.

Safe Strength of Portland Cement Concretes in Direct Compression.

Proportions.	Pounds per square inch.	Tons per square foot.
1:2: 4	410	29
1:2½:5	360	25
1:3: 6	325	23
1:4: 8	260	18

These figures allow a factor of safety of six at the age of one month, or of eight at the age of six months. For a large mass foun-

dation, values one-eighth greater may be taken, and for vibrating or pounding loads, values one-half of those given.

For a varying character of pressure, the safe *compressive strength* of Portland cement, stone or gravel, concrete may be taken as follows, and fairly represents modern practice:

TABLE XXXIII.

SAFE COMPRESSIVE STRENGTH OF PORTLAND CEMENT CONCRETE FOR VARYING CHARACTER OF PRESSURE.

Character of Pressure.	Safe strength at 1 month of 1:2½:5 mixture. Lbs. per sq. in.	Tons per sq. in.
Direct compression on mass concrete...........	400	29
Compressive stress in reinforced beams........	625	45
Columns over 2 square feet in sectional area......	350	25
Columns under 2 square feet in sectional area....	300	22
Bearing of iron on concrete, such as bridge seats.	400	29
Cinder concrete in direct compression.........	150	11

When mass concrete or piers are subjected to vibrating or pounding loads, the factors of safety may be nearly doubled, and the working values given thus made very much lower.

The *modulus of elasticity* of concrete varies from 1,500,000 to 5,000,000 pounds per square inch. For ordinary mixtures of Portland cement concrete a general average value of 2,500,000 is sufficiently close for all practical purposes.

Some authorities give for the average ultimate *shearing strength* of concrete, for "vertical shear," as deduced from theory and tests, almost *one-half the strength in direct compression.** Shear here denotes the strength of the material against a sliding failure when tested as a rivet or bolt would be tested for shear. This does not refer to the complex action which occurs in the web of a beam, where there exist direct tensile and compressive stresses which at the neutral axis are equal in intensity to the vertical and horizontal shearing stresses. When "diagonal tension" is treated as shear, the strength should be *very nearly the same as the tensile strength* of the material determined in the usual way. The subject of shearing strength of concrete needs much more careful experimental study. There is not a great deal of definite knowledge on the subject. The results of tests by French and German authori-

* From data on experiments on direct shear in concrete conducted by Prof. Charles M. Spofford at the Massachusetts Institute of Technology, and by Professor Arthur N. Talbot at the University of Illinois.

ties give much lower values than those of recent tests in the United States. Some tests show vertical shear *twice the tensile strength.*

The *elastic limit* in compression is about 600, or 600, but it is sometimes assumed to be one-half or two-thirds the ultimate strength.

When used in reinforced Portland cement concrete work, the following are *safe average unit stresses,* in pounds per square inch, for the concrete, as recommended by good authorities. The factor of safety and coefficient of expansion are also given in addition to the stresses:

TABLE XXXIV.

Safe Average Unit Stresses for Reinforced Portland Cement Concrete Work.

	Concrete 1:2:4
Factor of safety	5
Direct compression	350 to 500
Compression fibers in a beam	500 to 700
Direct tension	50
Diagonal tension in a beam	50 to 75
Tension fibers in a beam (when tension is considered)	75
Modulus of elasticity	2,500,000
Vertical shear	175
Coefficient of expansion	0.0000064
Adhesion of cement mortar to steel	50 to 75
Ratio of moduluses of elasticity of concrete to steel	1 to 12

It will be understood that these are only *average stresses,* and will vary according to the kind of cement used, the nature of the aggregate and many other varying conditions. Various model and standard specifications are being issued, and many cities have definite requirements in their building laws which fix the stresses to be used.

The value 3,000,000 pounds per square inch for the modulus of elasticity has been used. As very recently established by experiment, 2,500,000 is found to more nearly represent the correct average value.

The foregoing values have been used for stone or gravel concretes. In the following table there are given the ultimate compressive strength and the modulus of elasticity of *cinder concretes,* taken from the Watertown Arsenal Tests of 1898:

TABLE XXXV.

Compressive Strength and Modulus of Elasticity of Cinder Concrete.

Mixture.			Average Crushing Strength. Pounds Per Square Inch.		Average Modulus of Elasticity Between Loads of 100 and 600 Pounds Per Square Inch.
Cement.	Cinders.	Sand.	One Month.	Three Months.	
1	1	3	1,540	2,050	2,540,000
1	2	3	1,098	1,634	....
1	2	4	904	1,325	....
1	2	5	724	1,094	1,040,000
1	3	6	529	788	....

504. CONTRACTION AND EXPANSION IN HARDENING.—To determine the shrinkage and swelling of cement mortars in hardening many experiments have been made, and the results indicate that when they set in the air they contract slightly and when they set in water they are likely to expand.

The amount of change in dimensions seems to vary directly with the richness of the mortar or cement, and the shrinkage of concrete seems generally to be less than that of mortar and approximately proportional to the amount of cement per unit volume, the sand and stone being unaffected.

When there is no reinforcement, shrinkage cracks are apt to appear in the finished work, and to prevent them the concrete is kept moistened for a while after being put in place.

Experiments have shown a .05 to .15 per cent shrinkage in a 1 to 3 mortar, hardened in air for from 2 to 4 months, and only a .01 per cent shrinkage in the same mortar reinforced with 5½ per cent of steel; and the shrinkage is still less for reinforced concrete.

505. LAYING CONCRETE IN FREEZING WEATHER.—Various forms of clauses are used in specifications for concrete dealing with the question of the effect of frost upon the materials used. For example, the clause may read, "No concrete shall be laid in freezing weather except by special arrangement with and under the supervision of the architect or engineer in charge of the work. Should it be necessary to put it in place in such weather, special arrangements must be made for heating all the ingredients of the mixtures, and for maintaining a temperature which will not allow the concrete to freeze until it has properly set."

Or again, the clause may read, "No concrete shall be exposed to frost until hard and dry, except that laid in large masses, or in heavy walls having faces whose appearance is of no consequence. No materials used in mass concrete laid in freezing weather shall contain any frost. All surfaces shall be protected from frost, and all parts of surface concrete which have frozen shall be removed before fresh concrete is laid upon them."

A good general rule is to avoid laying concrete of any kind in freezing weather, unless it is really necessary to do so. When, however, circumstances make it necessary, and when they warrant the extra expense, mass concrete, if made of Portland cement, may

be laid at almost any temperature, provided proper precaution is taken and careful inspection guaranteed.

Natural cement concrete should never be exposed to frost until thoroughly hard and dry.

There is considerable difference of opinion among American engineers regarding the injury to Portland cement concrete from freezing, or from alternate freezing and thawing; but as there are many examples of concrete construction which show serious injury from freezing, it would seem advisable, at least in the case of reinforced concrete construction, to lay it only when the temperature is above the freezing point.

The clause relating to this in the "Regulations of the Bureau of Building Inspection of the City of Philadelphia" in regard to "The Use of Reinforced Concrete," and a part of the revised building laws and ordinances of 1907, is as follows: "Concrete shall not be mixed or deposited in freezing weather, unless precautions are taken to avoid the use of material covered with ice or snow or that are in any other way unfit for use, and that further precautions are taken to prevent the concrete from freezing after being put in place. All forms under concrete so placed to remain until all evidences of frost are absent from the concrete and the natural hardening of the concrete has proceeded to the point of safety."

506. EFFECT OF SEA WATER UPON CONCRETES AND MORTARS.—Sea water has a decomposing action on all cements, concretes and other hydraulic products. The following is a summary of the principal conclusions reached by investigations of this subject, and notably by Monsieur R. Feret:

(1) The most injurious compounds in sea water are the sulphates.
(2) Portland cements used for concretes in sea water should have a low percentage of aluminum and lime.
(3) When gypsum is used to regulate the time of setting, only the smallest possible quantity should be added.
(4) Puzzolanic material has proved a valuable addition for mortars and concretes used in sea-water construction.
(5) Fine sand should never be used.
(6) The essential qualities for mortars and concretes used in sea-water constructions are density and imperviousness.

507. THE FIRE-RESISTING PROPERTIES OF CONCRETE.—A great many tests have been made to determine the fire-

proofing qualities or fire-resisting properties of cement concretes, and much has been written on the subject. Laboratory tests have been supplemented by the natural tests of unexpected large conflagrations, and something learned from each.

When stone concrete is subjected to great heat the outer surfaces expand, leaving the under parts comparatively unaffected, with the exception of some slight cracking or of a tendency to warp. This is because the concrete is a very poor conductor of heat. About an inch of the outside portion of the concrete mass also tends to disintegrate from the action of the heat, the strength and texture are affected unfavorably and there is frequently a spalling off of the surface. Sudden application of water at this time causes a washing away of the portions thus affected.

The relative resisting qualities of concrete made from cinder, stone (trap rock) and slag are usually taken in the order named. Limestones used in the aggregate tend to calcine under the action of the heat and to be thus destroyed if subjected to water, while gravel and granite used as part of the aggregate tend to spall because of the difference between their coefficient in expansion and that of the rest of the concrete mass.

In regard to reinforced concrete as a fire-resisting construction, it is reasonable to believe that, in view of the results obtained from recent tests and conflagrations, it should prove to be satisfactory. Severe tests have been made for beams, floor slabs and columns, using different systems of reinforcing. Some systems and mixtures have stood the tests, and some have failed, those failing usually owing their failure to such causes as insufficiently dried-out concrete, insufficient thickness of concrete over the metal, the use of broken stone containing a high percentage of lime, etc.

508. COST OF CONCRETE.—The first cost of the material does not control the total cost of the concrete as much as does the general character of the construction with the varying conditions accompanying it.

When the cost of the forms is relatively small, and when the concrete is laid in large masses, from $4 to $7 per cubic yard in place may be taken as the average limits of cost. If the conditions are favorable, if the prices charged for the materials are low and if the work is done by contract, the lower amount mentioned may be considered a fairly average cost; while if the operation is a small one,

and if the workmen are inexperienced, the cost may run up to the higher limit.

In work which is not of such a simple nature, and in which centering is required, as, for example, in arch construction, the limits may be raised to from $7 to $14 per cubic yard.

The cost may be increased still more in other kinds of concrete work to from $10 to $20 per cubic yard, according to the character of the construction and the treatment of the surfaces or faces. Certain relatively thin walls of buildings come under this head.

Such a great variation or range in price, from $4 to $24 per cubic yard, is explained by the fact that there is just as great a range in the conditions obtaining, due to the magnitude of the operations and to the character of the work, which also depends in turn upon the kind of labor and materials employed.

When all the conditions are known in advance, it is possible to make a very close estimate of the cost of concrete put in place, by estimating in detail the cost of each unit entering into the finished mixture, such as the cement, the sand, the gravel or broken stone and the labor, and then by combining the different unit costs.

The cost of cement varies largely with the demand. The cost of sand depends chiefly upon the distance it is hauled and upon the cost of screening. Variations in the cost of gravel and broken stone also depend largely upon the hauling, and, in the case of gravel, upon the cost of screening also. The cost of labor in mixing, moving and depositing the concrete depends upon the methods employed and upon the extent to which the labor may be called skilled or experienced. The cost of the labor on forms varies between wide limits, and depends upon the character of the concrete work, such as the thicknesses of walls, the extent of face areas, the amount of reinforcing, etc.

Close estimates of the cost of the units, as outlined above, are now available, and may be found worked out in great detail in the various treatises on concrete construction. After determining the cost of each ingredient per unit used, such as the cement, sand and gravel or broken stone, and knowing the proportions of the mixture, the cost of each unit per cubic yard of concrete may be found from the table given in Article 500, "Quantities of Materials;" and by com-

bining these costs and adding the cost of labor per cubic yard the cost per cubic yard of the concrete put in place may be found.*

509. WEIGHT OF PORTLAND CEMENT CONCRETE.—The character of the materials, the degree of their compactness, their specific gravity and the proportions in which they are used affect the weight of concrete as well as that of mortar. Average weights may be taken as follows for Portland cement concretes:

Cinder Concrete	112 lbs. per cu. ft.
Sandstone Concrete	143 " " " "
Limestone Concrete	148 " " " "
Conglomerate Concrete	150 " " " "
Gravel Concrete	150 " " " "
Trap Concrete	155 " " " "

For practical purposes an average value of 145 pounds per cubic feet may be taken. The addition of reinforcing steel in the customary proportions usually adds from 3 to 5 pounds per cubic foot, so that the weight of reinforced concrete may be taken at 150 pounds per cubic foot.

510. MISCELLANEOUS DATA ON HANDLING CONCRETE.—The following valuable and useful data bearing upon this part of the subject have been compiled and condensed by Taylor & Thompson. They form part of a summary of general concrete data in their treatises on concrete and are reproduced here by permission:

TABLE XXXVI.

Miscellaneous Data on Handling Concrete.

Average load of broken stone or gravel for wood wheelbarrow	2.4 cu. ft.
Average load of sand for wood wheelbarrow	2.5 " "
Large load of broken stone or gravel for iron wheelbarrow on short haul in concrete work	3.0 " "
Large load of sand for iron wheelbarrow on short haul in concrete work	3.5 " "
Average load of ordinary concrete† for iron wheelbarrow	1.9 " "
Large load of ordinary concrete for iron wheelbarrow	2.2 " "
Number of shovelfuls of concrete per barrow in average load	13
Number of shovelfuls of concrete per barrow in large load	15
Average net time of one man filling wheelbarrow with concrete	1⅓ min.

* See also the "Architect's and Builder's Pocket-Book." F. E. Kidder. Chapter III, "Cost of Concrete and Materials Required per Yard."

See also for detailed estimates of cost of units of concrete and labor for same, "Concrete, Plain and Reinforced." Taylor & Thompson. Chapter II, "Approximate Cost of Concrete."

† All measurements of concrete are reduced to terms of quantity in place after ramming.

Quick net time of one man filling wheelbarrow with concrete.....	1 min.
Average quantity of concrete* mixed, wheeled 50 ft. and rammed, per man, per day of 10 hours†..............................	2.2 cu. yds.
Large quantity of concrete* mixed, wheeled 50 ft. and rammed, per man, per day of 10 hours†..............................	3 " "
Average quantity of concrete* laid as above with a gang of 15 men per day of 10 hours†..................................	33 " "
Large quantity of concrete* laid as above with a gang of 15 men per day of 10 hours†....................................	47 " "
Approximate average quantity of concrete* levelled and rammed, in 6-inch layers, per man, per day of 10 hours...............	11 " "
Approximate large quantity of concrete* levelled and rammed, in 6-inch layers, per man, per day of 10 hours...............	16 " "
Approximate average surface of rough braced plank forms built and removed by one carpenter per day of 10 hours..........	25 sq. yds.

511. EXAMPLES OF PORTLAND CEMENT CONCRETE. —Foundations of Mutual Life Insurance Company's building, New York: 1 part cement, 3 parts sand, 5 parts broken stone.

Foundations of United States Naval Observatory, Georgetown, D. C.: 1 part cement, 2½ parts sand, 3 parts gravel, 5 parts broken stone. [1 barrel of cement, 380 pounds, made 1.18 yards of concrete.]

Foundations of Cathedral of St. John the Divine, New York. Proportions: 1 part Portland cement, 2 parts sand, 3 parts quartz gravel, 1½ to 2 inches in diameter. [17,000 barrels of cement made 11,000 yards of concrete.]

Filling of caissons, Johnston building (fifteen stories), New York: 1 part Portland cement, 3 parts sand, 7 parts stone, finished on top for brickwork with 1 part cement and 3 parts gravel.

Manhattan Life Insurance Company's building, New York, filling of caissons: 1 part Alsen's Portland cement, 2 parts sand, 4 parts broken stone.

Professor Ira O. Baker states that the concrete foundations under the Washington Monument were made of 1 part Portland cement, 2 parts sand, 3 parts gravel and 4 parts broken stone, and that this mixture stood, at six months old, a load of 2,000 pounds per square inch, or 144 tons per square foot.

512. SPECIFICATIONS FOR CONCRETES.—Numerous specifications have been prepared and published for different kinds

* All measurements of concrete are reduced to terms of quantity in place after ramming.

† Note that the levelling and ramming, but not the labor on forms, are included in this item.

of concrete by many communities, societies, engineers, authors of treatises on cements and concretes, building departments, etc., both for mass concrete and for reinforced concrete. They represent the latest standard practice, and those for reinforced work include also the specifications for first-class or high steel with recommendations made to safely adapt this important material to reinforced concrete construction.

It is not possible in this condensed hand-book to reproduce these various specifications. For the proportions of materials for average conditions the reader is referred to Article 499 and for some brief specification forms to Chapter XIII, "Specifications."

513. CLASSES OF CONCRETE CONSTRUCTION.—When applied to building construction, concrete work may be classified under three general heads:

Mass or Massive Concrete Construction, which is without any metal reinforcing materials, or which has so little reinforcement that the tensile stresses are very slightly resisted.

Reinforced Concrete Construction, which has metal reinforcing materials arranged to fully resist the tensile stresses, and when necessary arranged also to partially resist the compressive and shearing stresses developed.

Concrete Block Construction, which consists of concrete wall blocks, molded or cast in various forms, and which includes also facings, ornaments, sills, caps, lintels, etc., molded or cast from concrete.

2. MASS CONCRETE CONSTRUCTION.

514. EARLY EXAMPLES AND USES OF MASS CONCRETE.—A brief description of mass concrete has been given in the definition. It is used principally in the construction of footings, supporting walls below and above grade, cores of walls, retaining-walls, reservoir walls, breakwaters, dikes, piers, heavy columns, machinery supports, sidewalks, arches, domes and many other constructions in which a heavy mass is the prime requisite. Concrete composed of broken stone, fragments of brick, pottery, gravel and sand, held together by being mixed with lime, cement, asphaltum or other binding substances, has been used in construction for many ages to resist compressive stress.

The Romans used it more extensively than any other material, as

the great masses of concrete once the foundations of large temples, palaces and baths, the domes, arches and vaultings still existing, together with the cores or interior portions of nearly all the ancient brick-faced walls found in Rome, testify.

In France, in the forest of Fontainebleau, there are three miles of continuous arches, some of them fifty feet high, part of an aqueduct constructed of concrete and formed in a single structure without joint or seam. A Gothic church at Vezinet, near Paris, which has a spire 130 feet high, is a monolith of concrete. The lighthouse at Port Said, Egypt, is another monolithic structure, 180 feet in height.

The breakwaters at Port Said, Marseilles, Dover and other important ports are formed of immense blocks of concrete. The water pipes and aqueduct at Nice, and the Paris sewers, are also notable constructions of the same material.

In England and France thousands of dwellings have been built of concrete, in place of brick and stone. Many of these are now standing, and some have stood for almost a century, without the least sign of decay. In the United States, until quite recently, the number of concrete buildings was comparatively small.

The architects, engineers and capitalists of the United States appeared for a long time to be more timid than those of any other nation in availing themselves of the use of concrete as a building material; and it is only since the year 1885 that it has been used to any extent in this country in the construction of buildings except for the footings of foundation walls.

Suitable materials for making concrete are available in almost every locality, and in most places solid walls of concrete are cheaper and more enduring than those of brick or stone.

For many years perhaps the best known of all concrete buildings in the United States were the hotels Ponce de Leon and Alcazar, at St. Augustine, Florida, Messrs. Carrère & Hastings, architects.

These buildings, composed entirely of concrete, presented an early example in this country of the almost limitless use to which concrete can be put.

For the construction of these hotels an elevator was built at a central point of the operation, to the full height of the intended buildings, and as the walls progressed, story upon story, runways were made to each floor, and the concrete, mixed by two capacious

mixing machines on the ground level, was lifted in barrels and run off to the place of deposit, enormous quantities of cement being used in the concrete in a single day.

The time transpiring between the wetting of the concrete and the final running in place, even at the fifth story, was not more than ten minutes at any time.

The concrete was composed of 1 part of imported Portland cement, 2 parts of sand and 3 parts of coquina, the greater part passing through a ½-inch mesh.

The cost of the concrete in place was about $8 a yard, including arches, columns, etc. In plain thick walls the cost was often much less.

In the basement of the Alcazar is a bathing pool 100 feet long, 60 feet wide and from 3 to 10 feet deep, all made of concrete. Rising from this pool are concrete columns, 6 feet square at the base and 40 feet high. They support concrete beams of 25 feet span, hollowed out in arch form and supporting the glazed roof covering the interior court.

515. MATERIALS USED IN MASS CONCRETE CONSTRUCTION AND THEIR PROPORTIONS.—These have been considered in Articles 498, 499 and 500, in the discussion of concretes in general.

A good average mixture for use in mass concrete construction is composed of 1 part of Portland cement, 3 parts of sand and 6 parts of broken stone.

For concrete mass work under ground and away from the action of the atmosphere, a puzzolan cement may be used; and the stone should be preferably a crushed hard sandstone or other fire-resisting stone in graded sizes of from ¼ to 2½ inches.

516. MIXING AND PLACING CONCRETE FOR MASS CONSTRUCTION.—These details have been considered in Articles 501 and 502. In addition to what has been said regarding the placing of concrete, reference may here be made to the depositing of concrete for mass construction under water. It must be put in place without separating the different materials. This is accomplished by lowering it in large buckets, passing it through tubes extending to the work, or depositing it in paper bags or in cloth sacks.

In the construction of breakwaters, sea-wall foundations for

lighthouses, piers, dikes, etc., the concrete is often molded into heavy blocks and then placed in position in the same manner as that in which stone masonry is laid, by means of a stationary or floating derrick, if water can be excluded from the site. If the water cannot be excluded the blocks are thrown in at random.

Blocks of concrete weighing 40 tons have been molded for this purpose and set in place.

517. MOLDS AND FORMS FOR PLACING MASS CONCRETE CONSTRUCTION.—*General Considerations.*—In almost all cases it is necessary, in order to confine concrete in place or in the desired form, to use molds or forms which prevent it from running while wet and soft. Wood is usually employed for this purpose, both below and above ground, although occasionally, for small heights, the earth itself is all that holds the concrete in place.

Very much that is said concerning the principles of mold or form construction for mass concrete may be said also of these details necessary for reinforced concrete construction.

The items of molds, forms and centering necessary for the erection of plain or reinforced concrete construction are important ones, and the expense of constructing them forms a large part of the total cost of the work.

Weak forms, also, constitute one of the four principal causes to which have been attributed the failures in some concrete buildings. These causes are (1) imperfect design, (2) poor materials, (3) faulty construction and (4) weak forms.

Materials Used for Forms.—White pine is the best wood for forms, and should be used for ornamental construction and fine face work. It is better not to use kiln-dried wood, as it absorbs much moisture; and better not to use very green lumber, as joints open or remain open. Medium dry lumber is therefore the best for this purpose. For panel work and all ordinary work, because of the expense of white pine, some other woods may be substituted, such as the soft varieties of the Southern pines, or Norway pine, spruce or fir. Some of these woods are more suitable than white pine for struts and braces, although they have a greater tendency to warp. They are, as a rule, stiffer than the white pines.

Thickness of Wood for Forms.—Regarding the thickness of lumber used for forms, custom differs with contractors and locali-

ties. Figured in commercial thicknesses measured before planing, in some cases a 1-inch thickness is used, in others a 1½-inch thickness and in a few others a 2-inch thickness, even for such work as panel forms.

"For ordinary walls 1½-inch stuff is good, although for heavy construction where derricks are used 2-inch stuff is preferable; while for small panels 1-inch boards are lighter and easier to handle. For floor panels 1-inch boards are most common, although if the building is eight or more stories in height 1-inch stuff of soft wood is likely to be pretty well worn out before the top of the building is reached, and the under surface of the concrete will show the wear badly. For sides of girders either 1-inch or 1½-inch stuff is sufficient, while 2-inch stuff is preferable for the bottoms of girders. Column forms are generally made of 2-inch plank."*

Miscellaneous Details Regarding Wood Forms.—All forms should be so designed that they may be put up and moved quickly, used over again as many times as possible and removed with as little damage as possible to the concrete or to the wood itself.

Forms must be strong enough to hold any loads that may come upon them or upon the concrete and strong enough to have a rigidity sufficient to prevent deflection while the concrete is being put in place.

For exposed faces the surfaces next to the concrete is dressed. The forms should be sufficiently tight to prevent loss of the wet material. Tongued-and-grooved sheeting surfaced on both sides is used, but is not required for heavy work.

All dirt, sawdust, shavings, etc., should be cleaned from the forms before the concrete is deposited, and forms should be cleaned before being used again.

In order to prevent the adhesion of the concrete to the wood forms, crude oil or "sludge" is generally recommended. Linseed oil, soft-soap and various other greasy substances are used also for this purpose. Oil should be thin enough to flow and fill the grain of the wood, thus acting as a filler.

Sharp corners should be avoided as much as possible, as the wood is apt to stick to them; and wherever practicable they should be slightly splayed to facilitate the removal of the forms.

* Sanford E. Thompson, in paper on "Forms for Concrete Construction," read before the Third Annual Convention of the National Association of Cement Users.

No forms should be removed from reinforced concrete work before the architect or engineer in charge has been notified. For ordinary and mass concrete work, as well as for reinforced concrete work, the best contractors have definite rules for the minimum time required for forms to be left in place in ordinary weather, and these periods are lengthened for changes in conditions according to the judgment of the superintendent in charge.

In the paper above referred to, Mr. Sanford E. Thompson makes the following statement regarding the proper time to move the forms in concrete work:

"Conference with a number of prominent contractors in various parts of the country indicates substantial agreement regarding the minimum time for leaving in forms. As a guide to practice the following rules are suggested, in the main the requirements of the Aberthaw Construction Company:

"Walls in mass work: one to three days, or until the concrete will bear the pressure of the thumb without indentation.

"Thin walls: in summer, two days; in cold weather, five days.

"Slabs up to 6 feet span: in summer, six days; in cold weather, two weeks.

"Beams and girders and long-span slabs: in summer, ten days or two weeks; in cold weather, from three weeks to one month. If shores are left without disturbing them, the time of removal of the sheeting in summer may be reduced to one week.

"Column forms: in summer, two days; in cold weather, four days, provided girders are shored to prevent appreciable weight weakening columns.

"Conduits: two or three days, provided there is not a heavy fill upon them.

"Arches: of small size, one week; for large arches with heavy dead load, one month."

"A very important exception to these rules applies to concrete which has been frozen after placing, or has been maintained at a temperature just above freezing. In such cases the forms must be left in place until after warm weather comes, and then until the concrete has thoroughly dried out and hardened."*

518. EXAMPLES OF FORMS FOR MASS CONCRETE

* "Reinforced Concrete in Factory Construction," published by the Atlas Portland Cement Company, New York.

CONSTRUCTION.—In this article some illustrations of typical wooden forms for mass concrete construction are given, and they represent also the types used for similar and appropriate parts of reinforced concrete buildings.

Concrete walls are often monolithic structures, molded in place, in forms made of planks and frames, with numerous uprights and struts, cross-ties and bolts. The forms may be constructed as they are for columns, between wooden sides extending the entire height of a wall; or they may be built in panels all the way up on one side, the other side being brought up as the concreting proceeds; or the

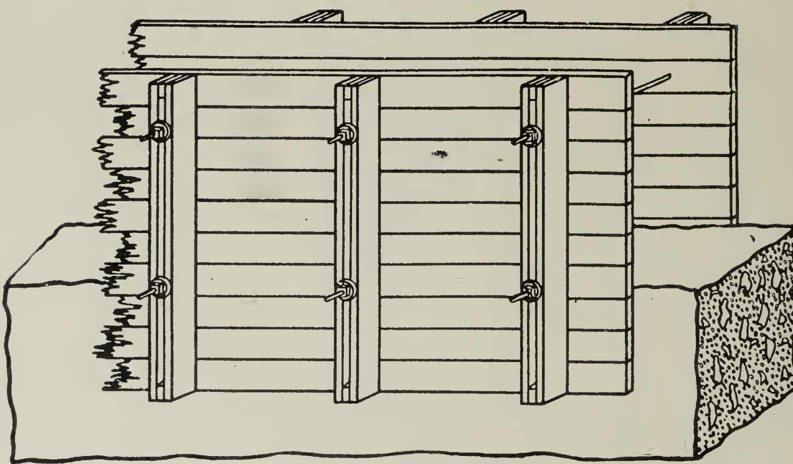


Fig. 466. Forms for Concrete Wall. Pacific Coast Borax Refinery, Bayonne, N. J.

uprights may be fixed in place, and several sections of sheeting used at a time, the lower ones being removed from the hardened concrete and placed on top of the one last set and the concrete then carried on up. When hollow walls are constructed core-boxes, in addition to the usual side forms, are employed. For forms erected complete before the concreting is begun, fairly wet mixtures are recommended; and for forms with movable panels, dry concretes are better. Different kinds of ties, some patented, are used to hold the side walls of the forms together, and when the latter are removed the nuts or castings are often screwed off, leaving the bolts or ties in the wall.

Fig. 466* shows the wood form used in the walls for the con-

* This figure, as well as several others in the chapter, are reproduced from "Reinforced Concrete in Factory Construction" and from "Concrete Construction About the Home and Farm," by permission, through the courtesy of the Atlas Portland Cement Company, of New York.

struction of the Pacific Coast Borax building at Bayonne, N. J., erected in 1897 and 1898, and one of the very first reinforced concrete factory buildings in the United States. These forms, patented by Mr. Ernest L. Ransome, the designer and builder of the factory, are still used in wall construction. The special feature is the vertical standard made of two 1 by 6-inch boards on edge with a slot between, through which the bolts pass. By loosening the nuts the planks behind the standards are loosened and the standards raised. In this building the walls were built in sections 4 feet high with central cores to form the hollow walls. White pine was used for the forms, and it is stated that the salvage on the lumber probably did not amount to more than 10 per cent, although by present methods the builders usually figure about 30 per cent.

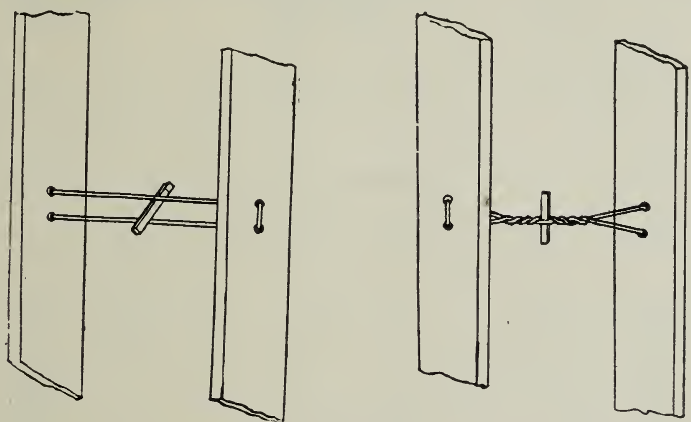


Fig. 467. Device for Preventing Wood Forms from Bulging.

Fig. 467 illustrates a simple expedient used to prevent wood wall forms from bulging. Through two holes bored in both sides of the form a wire is passed, the ends of which are tied together. A piece of wood or a large nail is then used to twist the two strands of the wire together. In this way the forms can be drawn together and held securely in place. When the forms are ready to be removed, the wires are cut at the sides and trimmed off even with the wall surfaces, or they are cut off about an inch back of the finished surfaces and the ends covered with cement mortar to prevent discoloration of the concrete by the corrosion of the metal.

Fig. 468 shows the side elevation of ordinary wood forms for a concrete wall, the braces being made of 2 by 4-inch pieces placed

against the 2 by 4-inch studs, as shown in Fig. 469. The construction as shown in the figure has defects which should be noticed. The braces should butt against the studs instead of being nailed to their sides, and the lower ends of the braces should rest against

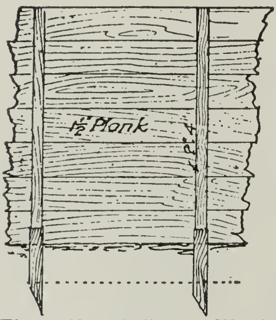


Fig. 468. Ordinary Wood Forms for Concrete Wall. Side Elevation.

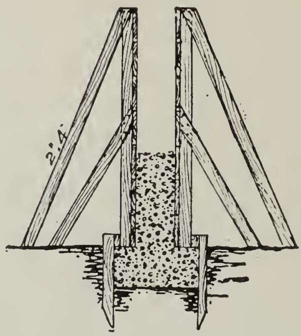


Fig. 469. Cross-section of Concrete Wall Footing, Wood Forms, Studs and Braces.

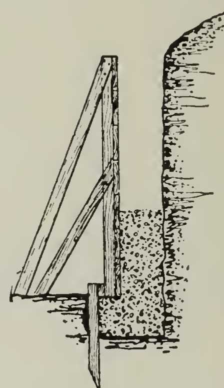


Fig. 470. Use of Clay Bank for Part of Forms.

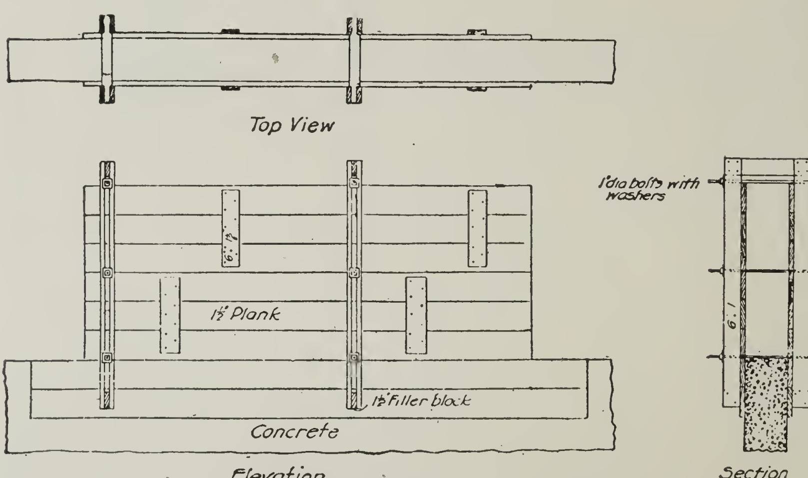


Fig. 471. Movable Wood Forms for Concrete Wall.

small stakes or posts or on sills instead of simply resting on the ground.

Fig. 469 shows the cross-section of an ordinary low concrete wall in course of construction, with the wood forms, studs and bracing. The concrete wall footing also is shown.

Fig. 470 shows a cross-section of a low concrete wall and footing

built against a bank of hard clayey soil. In this case the bank is made to do duty for half the form.

The faults pointed out for Fig. 468 are seen in Figs. 469 and 470 also.

Fig. 471 shows the elevation, section and top view of one kind of movable form used in building solid concrete walls of any height. The form is put in place and filled with concrete; and after the latter has set, the bolts are withdrawn and the form raised high enough to allow its lower part to overlap and the lowest set of bolts to rest on the completed concrete wall. This assists in keeping the wall plumb. The bolts are well greased each time to facilitate their

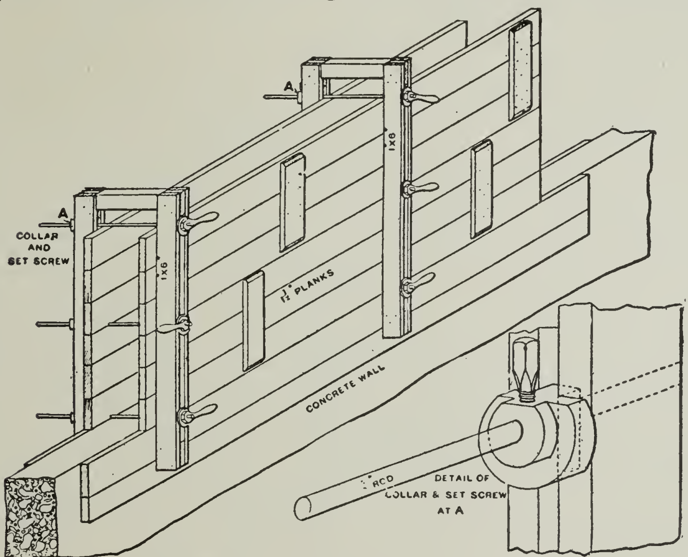


Fig. 472. Movable Wood Forms for Concrete Wall.

removal after the concrete has set; and the holes left are filled with mortar made with the same proportions of cement and sand used in the concrete.

Fig. 472 shows another view of a similar form, with detail of collar and set-screw sometimes used instead of the ordinary threaded bolt with nut and washer, where walls or columns are of various dimensions.

Fig. 473* shows another style of wood forms used for heavy

* This Fig. 473 and Figs. 474 and 475 also are reproduced from "Concrete, Plain and Reinforced," by Taylor & Thompson, by permission, through the courtesy of the authors. In this work much valuable information and many illustrations relating to forms will be found.

concrete wall construction, in which the ties consist of wire twisted to hold the side forms in place. This is the method illustrated also in Fig. 467. This is an inexpensive method of connection.

Fig. 474 shows a simple form for a concrete foundation wall. The following description is given by the authors of the work referred to in the footnote for Fig. 473: "A ranger, AA, is lined, and lightly spiked to occasional studs whose pointed ends are driven into the ground, and kept in line by strips of wood running from it to

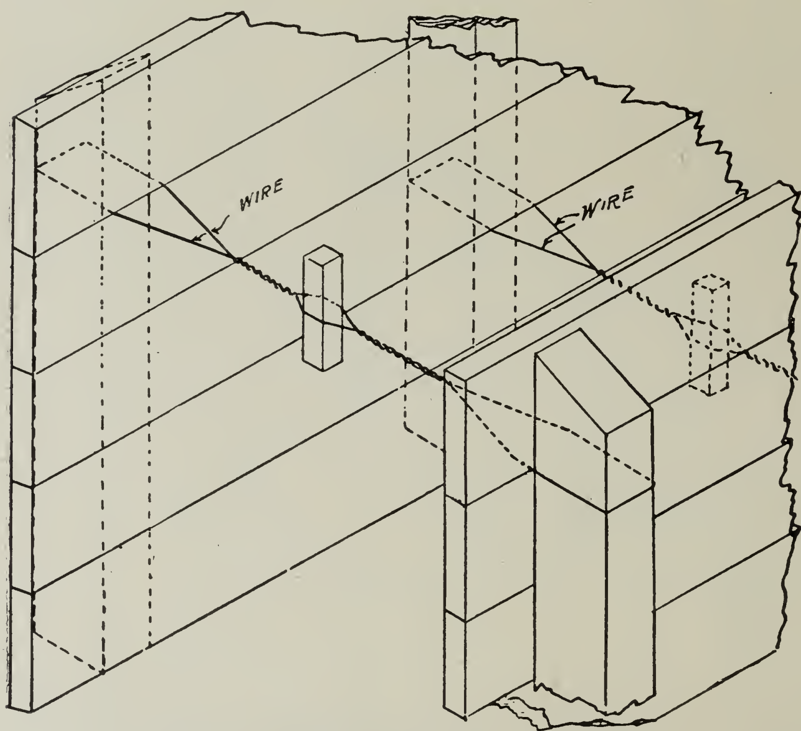


Fig. 473. Wood Forms for Heavy Concrete Wall.

stakes in the bank. In some cases it may be advisable also to set a lower ranger between the studs and the bank. Occasional stakes, BB, are driven into the ground, and a ranger, CC, for the inside row of studs, is laid on top of them, lined, and lightly spiked to them, while the upper ends of these studs are held by cleats, DD, run across to the inner row of studs. Vertical strips, EE, about ⅞ of an inch square, are placed inside of each stud for the form planks to rest against, and after a section of concrete is laid are easily

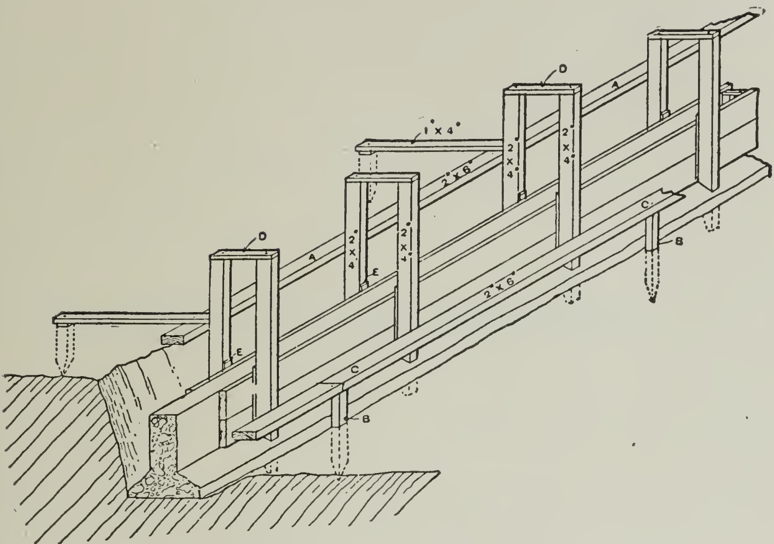


Fig. 474. Simple Wood Forms for Concrete Wall.

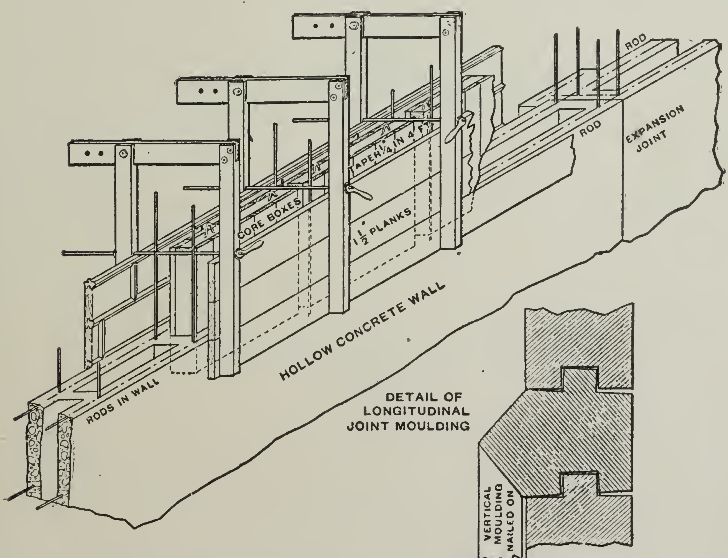


Fig. 475. Wood Forms for Hollow Outside Concrete Wall.

knocked out and the form planks raised to another level. The first layer of concrete is allowed to flow out under the lower plank to form a footing, above which the cellar floor is laid. The number of laborers and the height of the forms should be such that the planks

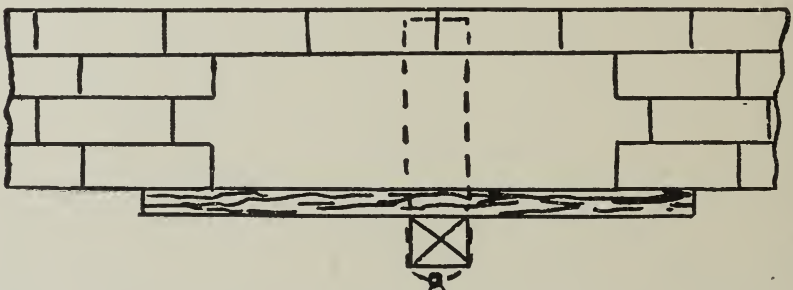


Fig. 476. Single Wood Form Shutter for Concrete Column in Brick Outside Wall.

may be raised each morning, provided the concrete is hard enough to withstand the pressure of the thumb without being indented."

Fig. 475 shows a design for wood forms for a hollow concrete wall. The arrangement of the ribs and bolts is such that the bolts do not have to pass through the concrete. When the concrete reaches the level of the bolt the forms are raised.

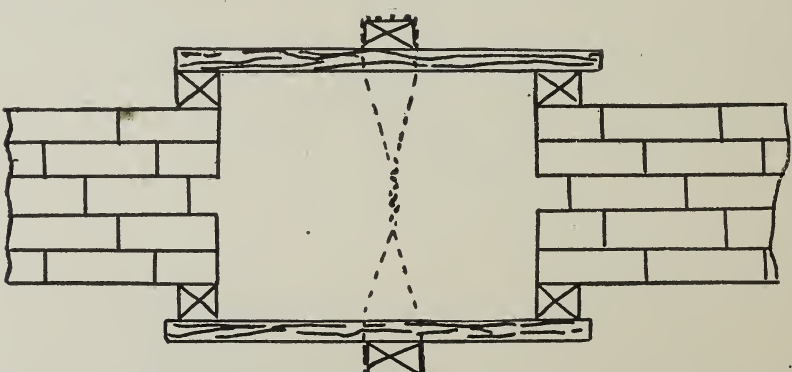


Fig. 477. Double Wood Form Shutters for Concrete Column in Brick Party-wall.

The sectional drawing at the right in the figure illustrates a tongued-and-grooved molding with edges slightly bevelled. This serves to form the horizontal joints, and takes the place of the triangular strips often nailed on the planks when the surfaces are not finished to show the monolithic construction.

Figs. 476, 477 and 478* show methods employed to save form materials in a building in which the walls were of brick and the columns, girders and beams of concrete. The brickwork was erected first and proper recesses and flue-like openings were left for the concrete columns, girders, etc. In this way the sides of the recesses served the purpose of two or three sides of the wood forms, and into these recesses the wet concrete was poured, reinforced or not, as required.

Fig. 476 is a horizontal section of an outside wall column recess showing side slats in the brickwork for anchoring or binding the concrete column and wooden form "shutter" with upright and wire ties.

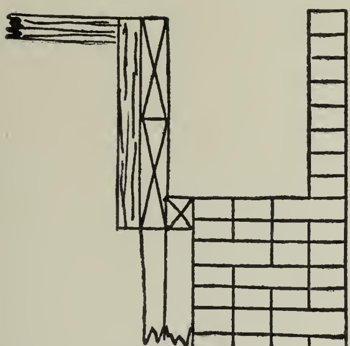


Fig. 478. Wood Side Form for Concrete Girder in Brick Wall.

Fig. 477 is a horizontal section of a party-wall column recess showing side slots, uprights, furring pieces, wooden form "shutters," wire ties, etc.

Fig. 478 shows a vertical section of a recess left for outside wall concrete girder, with wooden side form "shutters," supports for same, etc.

For columns it is necessary to make a form for each side, and to place frames around these side forms at intervals determined by the pressure to be resisted. The frames are secured in various ways, by bolts running through the ends of the pieces, by blocks and wedges, by hooks and staples, etc. Two by 4-inch pieces are generally used for the frames, and the side forms vary in thickness from ⅞ of an inch to varying greater thicknesses.

Fig. 479 shows the forms used for the concrete columns of the machine shops for the Bullock Electric Company, at Norwood, Ohio. The column band or clamps were of 2 by 4-inch stuff, and all the forms were of yellow pine, costing $20 per thousand feet. For the beam and column panel forms 1 by 6-inch tongued-and-grooved stock was employed, and this was planed on one side and on the edges. The column bands or clamps were held together by blocks and wedges, as shown on the drawing. On one side the piece was

* Figs. 476, 477 and 478 are reproduced through the courtesy of the *Cement Age*, June, 1906. They appeared also in a paper on "Cost Reduction of Reinforced Concrete Work," by Mr. E. P. Goodrich, read before the Association of American Portland Cement Manufacturers, at Atlantic City, N. J., in June, 1906.

loose, so that the same clamp could be used for a narrower column by changing the position of the blocks. The clamps were spaced 18 inches apart near the bottom, the intervals increasing to 24 inches near the top.

519. CONCRETE FOUNDATIONS AND CELLAR WALLS FOR LIGHT BUILDINGS.—*General Considerations.*—For the foundation and cellar walls of frame buildings concrete can be used to great advantage *by the carpenter,* because all of the lumber required for the forms can afterward be used in the construction of the superstructure, which means a considerable saving in the cost

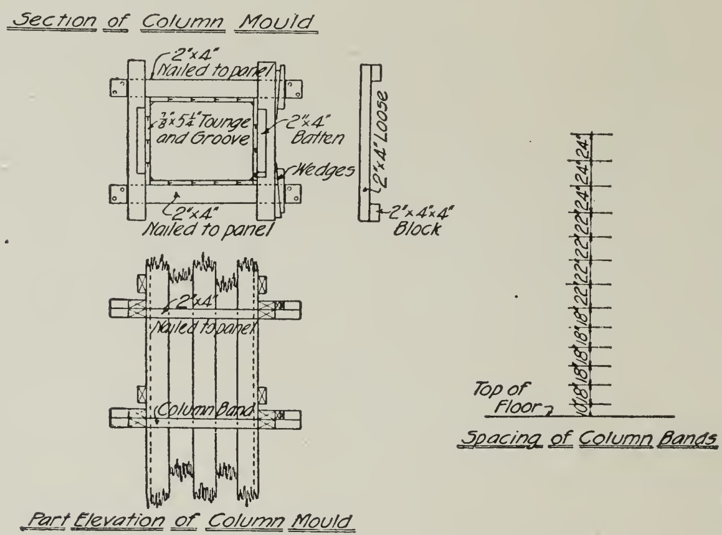


Fig. 479. Wood Forms for Concrete Columns.

of the walls. By using concrete the carpenter can start his work from the ground and have full control over it. He can also build the chimneys of the same material, and in this way no other mechanics are required about the building until it is ready for painting and plastering.

Requisite Dimensions for Concrete Walls and Footings for Light Buildings.—The requisite thickness of concrete walls naturally depends in a great measure upon the quality of the concrete, whether or not it is reinforced, and the purpose for which the walls are to be used. Messrs. Taylor & Thompson state that "a single concrete wall, 4 inches thick, with its base spread to provide a footing,

is at least equivalent to an 8-inch brick wall; and a 6-inch concrete wall is at least equivalent to 12 inches of brick."*

They recommend, however, that all walls 6 inches thick and under be reinforced with small rods, about ¼ of an inch in diameter, placed from 18 inches to 2 feet apart, not only to increase their permanent strength, but to guard against accidents during or immediately after construction.

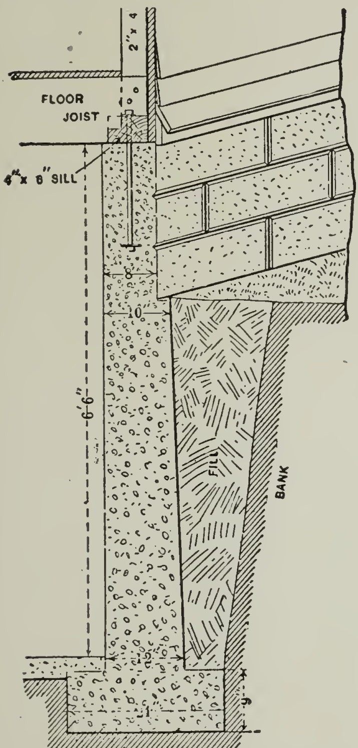


Fig. 480. Typical Concrete Cellar Wall and Footing for Frame Building.

The writer's experience with cement walls leads him to believe that the foregoing statement regarding the comparative thickness of concrete and brick walls has not been overestimated as far as the strength and stiffness are concerned; but it is often necessary to make walls thicker than is absolutely required for strength. A 4-inch wall of ordinary concrete is likely to be penetrated by moisture in a severe rainstorm, and it has little stability to withstand a thrust unless reinforced by piers or buttresses.

For cellar and foundation walls, therefore, the writer would not recommend a thickness less than 8 inches, except for very small buildings. Interior partitions supporting floors may be 6 inches thick, and partitions which support no weight may be made as thin as 3 inches.

Foundation Walls for Small Buildings.—In Fig. 480 is shown a section through the cellar wall of a two-story frame building which is well adapted to clay soils in northern latitudes. In all soils which "heave" under the action of frost it is very desirable to batter the outer face of the wall, so that as the ground works up it comes away from the wall.

In dry soils and soils not affected by frost the walls may as well be plumb on the outside and of a uniform thickness of 8 inches.

* "Concrete, Plain and Reinforced." Taylor & Thompson.

For frame cottages, stables and small barns a wall such as shown in Fig. 481 will answer, and in localities where frost does not have to be taken into consideration, and where the ground is sufficiently firm to stand vertically, the cellar walls of small frame buildings can be built as shown in Fig. 482, the concrete being placed directly against the bank. In a wet climate the writer would not advise building a wall in this way.

It should always be kept in mind that the thinner the wall the stronger and denser should be the concrete.

It should be noticed that all walls shown have bolts imbedded for securing the plates or sills. These bolts cost very little and are easily

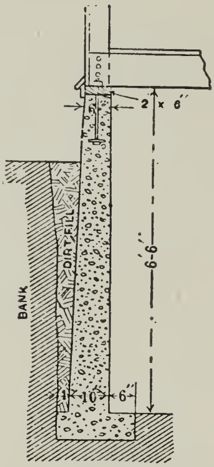


Fig. 481. Battered Concrete Cellar Wall. Light Building.

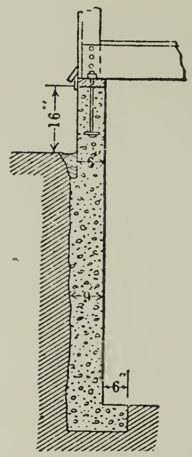


Fig. 482. Concrete Cellar Wall. Light Building. Firm Earth. No Frost.

built in, while they hold the plates or sills tightly to the wall and also strengthen it to resist the thrust of the dirt filling when there is no great weight on it.

Quantities and Cost of Concrete Walls.—Concrete work, except in walks and floors, is almost always measured by the cubic yard, of 27 cubic feet. Sand and gravel are commonly contracted for by the cubic yard, while crushed stone is sold by the ton and by the yard.

Knowing the cost per barrel of cement, and per yard of sand, gravel or broken stone, the cost of the ingredients per cubic yard of rammed concrete may be determined very closely by means of the following table:

TABLE XXXVII.

QUANTITIES REQUIRED TO MAKE A CUBIC YARD OF RAMMED CONCRETE.*

Proportions.			Quantities required per yard of concrete.		
Cement.	Sand.	Gravel or stone.	Cement.	Sand.	Gravel or stone.
Sack.	cu. ft.	cu. ft.	bbls.	yds.	yds.
1	1½	3	1.9	0.42	0.85
1	2	4	1.45	0.45	0.86
1	2	5	1.3	0.38	0.95
1	2½	5	1.2	0.45	0.90
1	3	6	1.0	0.40	0.92

Thus, if in any given locality cement costs $2 per barrel, sand 50 cents a yard, and coarse gravel 60 cents a yard, the cost per cubic yard of a 1:2:4 mixture will be:

For cement	1.45 × $2.00 =	2.90
For sand	0.45 × .50 =	.22½
For gravel	0.86 × .60 =	.51½

Total cost for materials, $3.64 per yard.

The cost of mixing concrete by hand and placing in forms for cellar walls from 8 to 12 inches thick should not exceed $1.50 per yard, with the wages at 17½ cents per hour; and with experience this may be reduced to $1.25 per yard. As a rule the thicker the body of concrete the cheaper it can be placed.

Forms for Concrete Cellar Walls for Light Buildings.—For the cellar walls of wooden buildings it will be more economical to build the forms of material that may be afterward used in constructing the building, and this can be done so that there will be little waste of lumber.

Fig. 483 shows a good and economical method for building the false work for the wall shown in Fig. 480, the lumber required being of those dimensions most extensively used in the construction of frame buildings.

For a wall of the section shown in Fig. 480 the footing should be put in before the wall forms are set up. Except in sand and gravel, no side pieces are required for footings, as all other soils will

* These figures may be considered as a fair average where the aggregate contains stone up to 2 inches in diameter. For finer aggregates slightly greater quantities of all materials are required.

Where gravel is used just as it comes from the bank, without the addition of sand, add together the items for sand and gravel.

stand vertically for a depth of 8 to 10 inches; hence all that is necessary is to dig the trench the exact width and depth required for the footings. The concrete is then placed in the trenches and tamped with a rammer, such as is shown in Fig. 486. The concrete for footings should be mixed just wet enough to have the water flush to the surface when tamped. This is not on account of considerations of strength, but because moderately dry concrete sets up quicker than wet concrete and is rather more convenient to handle.

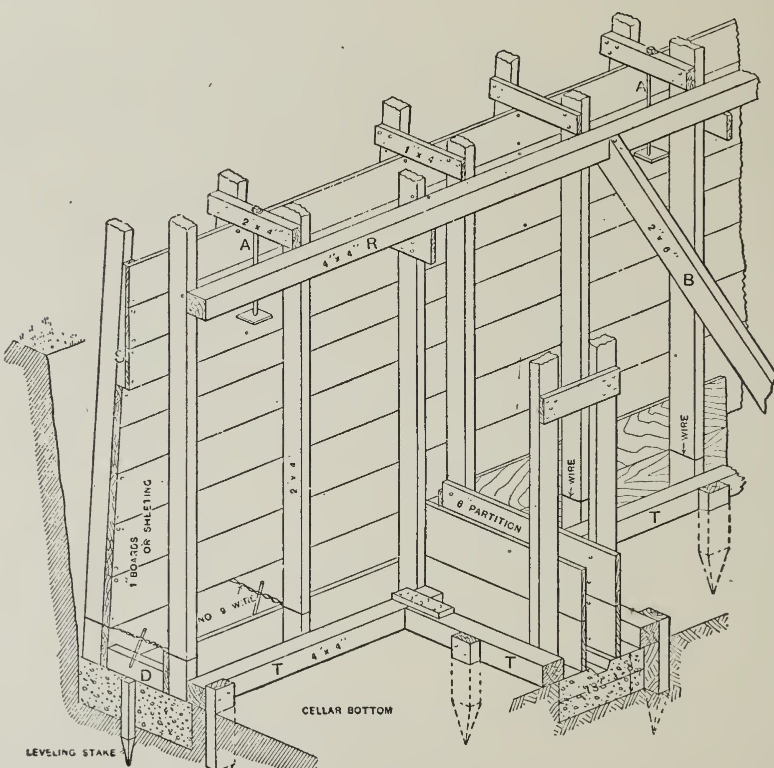


Fig. 483. Forms for Concrete Wall Shown in Fig. 480.

Before placing the concrete for footings it is a good idea to drive stakes in the trenches about 6 feet apart, with their tops levelled to give the exact height for the top of the footings.

The concrete can then be readily levelled with the tops of these stakes, which may be left in place without harm.

To start erecting the wall form, stringers TT should first be

carefully placed on the cellar bottom and secured by stakes in a position that will give the correct line for the inside of the wall when the uprights and sheeting are placed inside of them. Two uprights 12 or 16 feet apart are then set up, and another stringer secured to them at about the level of the top of the wall. These uprights should be carefully plumbed and well braced by diagonal braces nailed to short stakes driven in the cellar bottom. The two stringers then form a guide for the intermediate uprights, which can be quickly set up and lightly secured by nails. One sheeting board is then nailed to the bottom.

After the inner form is set up the outer one is easily erected and secured to the inner one as indicated.

On account of the proximity of the bank it will usually be found more economical to secure the bottom of the outer uprights by twisted wires, as shown in Fig. 483, an 8-inch board being first nailed along the bottom, and loose spacing blocks D laid in. The wires are than twisted until the outer form is brought tight against the spacing blocks. After the wall has set the wires can be cut with a chisel and the form pulled up. The spacing blocks, D, should be removed as the concrete is put in.

The outer form should be sheeted to the top of the bank before placing any concrete, but it is more convenient to place the sheeting on the inner form just ahead of the concrete to facilitate tamping.

If the building happens to be built on a sand or gravel bank it will also be cheaper to mix the concrete in the cellar, otherwise the concrete can be more cheaply mixed on the bank and wheeled to the forms.

The outer face of the wall above the bank is plumbed by nailing tapered pieces to the uprights, as shown at S.

If this portion of the wall is to be blocked, then a separate form can be used with greater economy than by using the same form and adapting it as just described.

At AA is shown the method of suspending the bolts which are to be imbedded in the concrete for securing the sill to the wall.

The top of the sheeting should be levelled at the exact height of the wall to form a guide for levelling the concrete.

It will be noticed that the method adopted for staying the uprights (Fig. 483) enables scantling of any length greater than the height

of the wall to be used, as 8 or 9-foot lengths, so that they can afterward be used for studding.

Fig. 484 shows the simplest method of building the forms for the wall shown by Fig. 481, the principal variations from the details shown in Fig. 483 being the manner in which the uprights are secured at the bottom. For the method shown in Fig. 484 the forms must be erected before the footings are put in, the sheeting being started 6 or 8 inches above the bottom of the trench and the concrete spread out under it. While this method is satisfactory

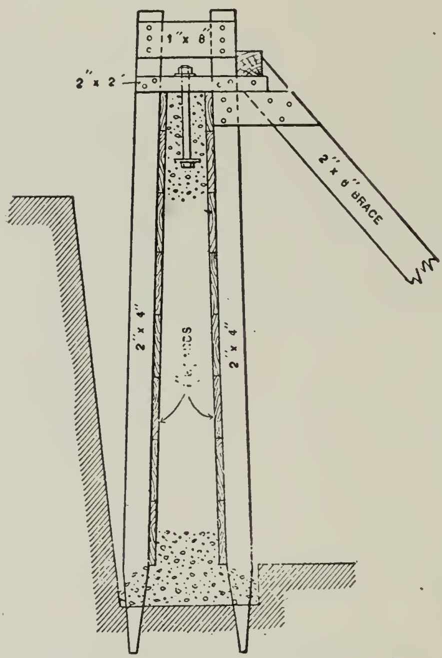


Fig. 484. Forms for Concrete Wall Shown in Fig. 481.

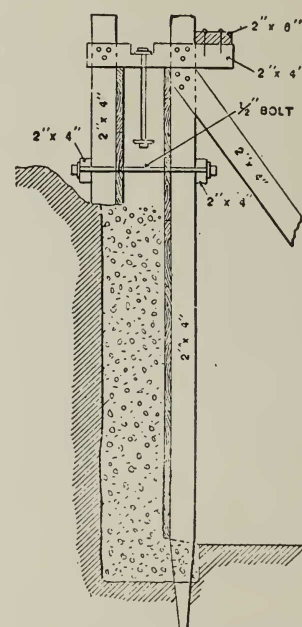


Fig. 485. Forms for Concrete Wall Shown in Fig. 482.

for a light wall, it is not as good as that shown by Fig. 483 for a heavy wall.

The bottoms of the uprights in Fig. 484 should be tapered from the bottom of the sheeting and planed, otherwise it will be difficult to withdraw them without breaking the concrete. It is also advisable to give the tapered ends a coat of crude oil.

Fig. 485 shows a method of erecting the forms when the concrete is placed directly against the earth. In this case the concrete should be put in to within about 6 or 10 inches of the top of the

bank before the outer form is set up. The outer form is secured at the bottom to the inner form by ½-inch bolts, about 3 feet apart, with spacing blocks between the forms to hold them the right distance apart. As the concrete is placed these spacing blocks should be taken out.

In starting the concrete between the forms the top of the concrete already in place should be well wet and covered with about ½ inch of thin mortar, mixed 1 to 1, cement and sand, to cause adhesion.

The erection of the forms for concrete work naturally admits of considerable variation in the details of construction and affords ample opportunity for the use of ingenuity and good judgment on the part of the contractor.

Thickness of Sheeting and Size and Spacing of Uprights for Forms for Light Buildings.—These dimensions should be governed somewhat by the character of the concrete work. The forms should be stiff enough so that they will not spring under the weight of the concrete or when the concrete is tamped. As a rule the pressure of wet concrete is considerably greater than that of dry concrete, although if the latter is properly tamped the effect on the forms is about the same. For a rough wall, built of wet concrete, a slight springing of the sheeting does no particular harm; but where a nice appearance is desired there should be no springing.

For the class of work shown in the accompanying illustrations the uprights should be spaced about 2 feet on centers where ⅞-inch boards are used for sheeting; but if plank sheeting is used, the uprights may be spaced 5 feet on centers.

With ⅞-inch sheeting 2 by 4's may be used for the uprights, but they should be braced about every 5 feet in height. In forms such as are shown in Figs. 483, 484 and 485, if the 2 by 4's show a tendency to spring they may be tied together through the wall by soft iron wire—baling wire will answer—twisted at the bottom of the form as shown in Fig. 483. This generally is cheaper than additional braces and is not in the way. If the forms do spring under the weight of the concrete they should be immediately braced to prevent further springing, but no attempt should be made to straighten them, as concrete should not be disturbed after it has commenced to set.

The sheeting should be nearly, although not absolutely, watertight, and should be free from knot holes, and the boards should

be in 8-inch or 10-inch widths and surfaced on the inner side.

Kind of Lumber Required.—For such forms as are described in this article either spruce, fir, hemlock or pine boards and scantlings may be used; and moderately green lumber will be found better than very dry lumber, as it is not as badly affected by the moisture in the concrete.

When Forms for Light Building Foundations May Be Removed.—Where there is no pressure against the wall the forms can generally be removed in from 24 to 48 hours after the wall is completed, or just as soon as the top concrete is so hard that it cannot be indented by the thumb. The sooner the forms are removed the less is the lumber affected.

After the forms are taken down the inside of the wall should be braced until the first floor is in place, to protect the wall from anything falling against it. If this is done the sill may be bolted on 24 hours after the wall is completed, and the floor joists set the next day; but no great weight should be placed on the wall until it is seven days old.

Cost of Form Work for Foundations for Light Buildings.—For the forms shown in this article the writer estimates that the cost of putting up and taking down, not including the lumber, is about 6 cents per square foot of wall, which for an average thickness of wall of 8 inches is equivalent to $2.40 per yard of concrete.

With a 1 to 7½ mixture, cement at $2 a barrel, gravel at 60 cents a yard, delivered at the site, common labor at 17½ cents an hour, and carpenters' wages at 30 cents an hour, the total cost of the cellar walls, averaging 8 inches thick, should approximate $7 per yard, or 17½ cents per superficial foot. This does not include the cost of the lumber, as it is assumed that this will be used in the superstructure. At $10 per thousand bricks in the wall, wall measure, an 8-inch common brick wall will cost 15 cents per square foot, and a 12-inch wall 22½ cents.

Rammers and Puddlers.—All concrete should be either tamped or puddled whenever practicable. For dry and medium mixtures thorough tamping is necessary in order to obtain a solid mass, and even with very wet mixtures pockets or voids may occur unless the mass is puddled. A mixture which does not quake in the wheelbarrow should be deposited in layers not over 6 inches thick, and thoroughly tamped or rammed with an iron rammer, such as is shown

in Fig. 486, in the first drawing. Against the forms a rammer such as is shown in the second drawing is more satisfactory.

A quaking mixture may be deposited in layers 10 to 12 inches thick, and should be puddled with a square-pointed spade or a rammer like that shown in the second drawing. A rammer such as is shown in the third drawing, made from a piece of 2 by 3-inch scantling, is very effective for many kinds of work, the rammer being shoved through the entire thickness of the mass.

For exposed walls built in forms the concrete next to the forms should be puddled by thrusting down next to the mold a square-pointed spade or a thin tool like a sidewalk scraper, as the concrete

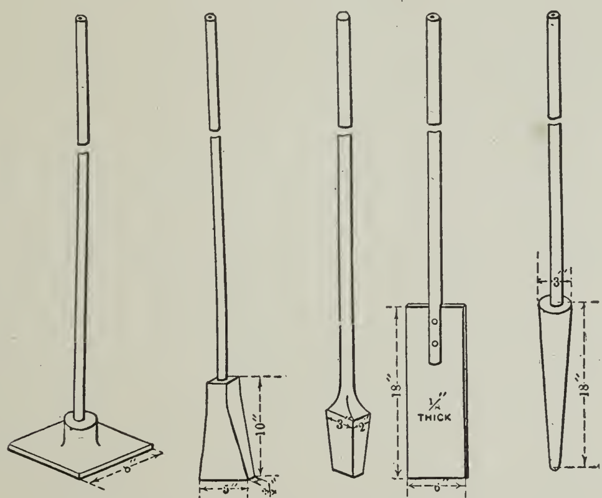


Fig. 486. Types of Rammers and Puddlers for Concrete.

is placed, working it up and down, and at the same time pushing back the large stones or pebbles so that the thinner mortar may run in and form a smooth and fairly uniform surface. Care must be taken, however, not to pry on the concrete so as to spring the molds. The fourth and fifth drawings of Fig. 486 show the tools used for puddling the concrete in the factory buildings of the United Shoe Machinery Company at Beverly, Mass.

The concrete was mixed quite wet and deposited in layers about 12 inches thick; and the tools were made so that they could penetrate 16 inches without covering their heads.

521. MASS CONCRETE AND REINFORCED CONCRETE CONSTRUCTION.—Many examples of mass concrete construc-

tion could be given and illustrated, but a sufficient number have been cited to explain the principles of this portion of the subject.

In the following third subdivision of this chapter, relating to "Reinforced Concrete Construction," other examples of buildings and parts of buildings are given, many of the details of which, aside from the reinforcement, serve also for mass concrete construction.

3. REINFORCED CONCRETE CONSTRUCTION.

522. DEFINITION OF REINFORCED CONCRETE.—As distinguished from "mass concrete" or "massive concrete," containing no metal reinforcement, reinforced concrete has already been defined in Article 513. Perhaps as good a definition as any is that given in the regulations of the New York Bureau of Buildings, and also in the building laws of Chicago, St. Louis, San Francisco, Buffalo and some other cities, which describe it as "an approved concrete mixture reinforced by steel of any shape, so combined that the steel will take up the tensional stresses and assist in the resistance to shear."

The terms "concrete-steel," "steel-concrete," "ferro-concrete," "armored concrete," etc., have also been used for this heterogeneous material, but are not now in general use.

523. SUBDIVISIONS OF REINFORCED CONCRETE CONSTRUCTION.—In considering or specifying this kind of work it is sometimes divided into two classes:* (1) "Monolithic Construction," or concrete molded in place, and (2) "Unit Construction," or concrete which is not molded in place, but which is manufactured at the factories, put together there in units, such as columns, girders, beams, slabs, etc., and then brought to the building and put in place.

I. DEFINITIONS, HISTORY, USES AND EXAMPLES.

524. HISTORICAL NOTES ON REINFORCED CONCRETE CONSTRUCTION.—In 1850 M. Lambot built a small boat of reinforced concrete, and in 1855 exhibited it at the Paris Exposition and took out patents.

In 1861 Joseph Monier, a gardener of Paris, constructed flower-pots, tubs, tanks and basins for use in horticulture, and François

* See "General Specifications for Concrete Work as Applied to Building Construction," by Wilbur J. Watson, Cleveland, Ohio.

Coignet explained his theories of reinforced concrete for beams, arches, large pipes, etc.

In 1867 both Monier and Coignet exhibited some work at the Paris Exposition, and Monier took out some patents on the new material. His system of construction, although somewhat changed and modified, is still used in slab reinforcement and other details. It consists essentially of two sets of parallel rods placed over and at right-angles to each other, forming a mesh or trellis. There was at that time, however, no general application of the principle or system to building construction and it was confined to very narrow fields.

In 1885 the German and Austrian engineers took the matter up, and G. A. Wyss and J. Bauschinger began a series of experiments and tests in constructions of the Monier system and in 1887 published the results together with formulas for use in design.

From 1887 on, Austria especially advanced the theory and practical design, and shortly after this, among those engineers who did the most to develop the new construction, was Melan, who used I-beams and T-beams to resist the compressive as well as the tensile stresses. Hundreds of arch bridges have been constructed after this system.

In Germany, although for some time government restrictions delayed the development of reinforced concrete in building construction, it is now extensively employed, over two hundred different types or systems being in use there in 1908.

In France neither Monier nor any of his countrymen appeared to appreciate the scientific value of his ideas; but many other types of tension and shear-resisting reinforcements were patented from time to time, and among those elements now widely used are those of the system introduced by Hennebique, who was probably the first to make use of "bent-up" bars and stirrups.

In England, as in the United States, the first applications of iron and steel to concrete reinforcements were due to efforts made to make floor construction fire-proof. Mr. Thaddeus P. Hyatt, a native of New Jersey, residing in England, conceived the idea of inserting iron rods near the lower surfaces of concrete beams to take up the tensional stresses, and in company with Dr. David Kirkaldy of London, he made some tests and published his very valuable conclusions in 1877.

In the United States the earliest example of a reinforced building was the building erected in 1875, near Port Chester, N. Y., by Mr. W. E. Ward. In this structure all the exterior and interior walls, floor-beams, roof, cornices, etc., were made entirely of concrete, reinforced with light iron beams and rods.

The early development of the new system took place in this country in California, where the pioneer experimenters were H. P. Jackson, E. L. Ransome and G. W. Percy. In 1877 Mr. Jackson applied Mr. Hyatt's invention to building construction, using thin iron blades, set horizontally on edge with round iron cross wires for the reinforcement. In 1884 and 1885 Ransome built a warehouse, a few years later a factory building, the building of the California Academy of Science in 1888 and 1889 and the Museum building of the Leland Stanford Junior University in 1892. (See Article 527.) The last two buildings mentioned were designed by Mr. Percy. Ransome used square-section bars of iron and steel for his reinforcements.

Edwin Thacher and F. von Emperger also were among the earliest constructors in reinforced concrete in the United States, doing much to introduce the system, especially in the building of bridges.

525. USES OF REINFORCED CONCRETE CONSTRUCTION.—While the improvement in reinforced concrete construction has been rapid during the past twenty years, it is since about the year 1896 that its development has been particularly remarkable. It is now, in 1908, looked upon by architects and engineers generally as a form of construction which is safe, if properly designed and conscientiously executed, and which has a constantly widening field of usefulness.

The constants necessary in calculations for different stress resistances have not yet been determined with sufficient definiteness, but very careful research is being made in this direction. What may be called a "common practice" may be said to have been established in some details, and for much design work many rational principles are at hand.

It is the general opinion of engineers and investigators that "good practice" in reinforced concrete construction will be established at no very distant time.

Various uses of reinforced concrete in building and engineering

construction have been mentioned in Article 497, in connection with concrete in general; and in Article 514 were given some early examples of mass concrete construction.

Reinforced concrete construction is advantageous to varying degrees in different types of structures. Some of the most important of these types are mentioned in this article, and in the following article the advantages accompanying its use in their design.

For this purpose the different types of structures may be conveniently classified as follows:* (1) Buildings, (2) Culverts and Small Girder Bridges, (3) Retaining-walls, Dams and Abutments, (4) Arch Bridges, (5) Reservoir Walls, Floors and Roofs, (6) Conduits and Pipe Lines, (7) Elevated Tanks, Bins, etc., (8) Chimneys and Towers, (9) Piles, Railroad Ties, etc.

526. ADVANTAGES OF REINFORCED CONCRETE IN CONSTRUCTION.—*For Buildings.*—Used now throughout for all parts; especially adapted to floor slabs, spread-footings in foundations, for which it is cheaper than I-beam footings imbedded in concrete; and used with constantly increasing skill and success for beams, girders and columns.

For Culverts and Small Girder Bridges.—Simpler and more economical than arches of masonry and more durable than bridges of steel.

For Retaining-walls, Dams and Abutments.—Frequently cheaper than ordinary masonry construction; adapted to a more economical type of design, such as reinforced concrete cantilever beams, for example, and thus developing the full compression strength of the material used; not dependent upon weight alone to resist lateral thrust; has whatever metal is used thoroughly covered and protected from corrosive agencies, which an all-steel frame has not.

For Arch Bridges.—Possesses fewer advantages or economies over ordinary masonry construction, because the prevailing stresses are principally compressive; reinforcements useful only to prevent cracks or to resist comparatively slight flexture stresses caused by moving loads.

For Reservoir Walls, Floors and Roofs.—Well adapted because lighter in design, and probably as durable as ordinary masonry.

For Conduits and Pipe Lines.—Well adapted to large sewers and

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* See "Principles of Reinforced Concrete Construction," by Turneaure and Maurer, in which treatise there is an excellent treatment of the subject.

water-conduits, and also occasionally used for pipe lines and tanks under pressure.

For Elevated Tanks, Bins, etc.—Durable and well suited to resist the lateral pressure against walls and heavy loads on floors, and often employed in the construction of entire structures of this kind.

For Chimneys and Towers.—More economical in design and more definite in stress calculations than brick and stone construction because of its monolithic character.

For Piles, Railroad Ties, etc.—Valuable substitute for wood in piles, especially when used where they would not be always entirely under water; possess several advantages over wood or steel for railroad ties.

527. EARLY EXAMPLES OF REINFORCED CONCRETE CONSTRUCTION.—*The Ransome Concrete Floors.*—Mr. E. L. Ransome patented his improvements in 1884, and after that time they were extensively used, especially in San Francisco.

The Ransome concrete floors were made in two forms—flat, as shown in Fig. 487, and recessed, or panelled, as shown in Fig. 488. These floors have been used for spans up to 34 feet. No floor beams were required, the floor being self-supporting from wall to wall (when the building was not more than 30 feet wide), or from wall to girder. The great strength of these floors was fully demonstrated by actual use in many heavy warehouses in various portions of California, as well as in many other buildings.

A section of a flat floor in the California Academy of Science, 15 by 22 feet, was tested in 1890 with a uniform load of 415 pounds per square foot and the load left in place for one month. The deflection in the middle of the 22-foot span was only ⅛ of an inch. It was estimated by the architects that the saving at that time by using this construction throughout the building, over the ordinary use of steel beams and hollow tile arches of the same strength, and with similar cement-finished floors on top, amounted to fifty cents per square foot of floor.

The flat construction shown in Fig. 487 was the best adapted of the two for office-buildings, hotels, etc., although the panelled floor shown in Fig. 488 had much the greater strength for the same amount of material. The latter construction was used in several warehouses in California without the use of any steel or iron beams or girders, and supported very heavy loads for many years.

The Leland Stanford Junior Museum, at Palo Alto, California. —This very large and costly building, mentioned before in Article 524, was also constructed entirely of concrete. It was built on the

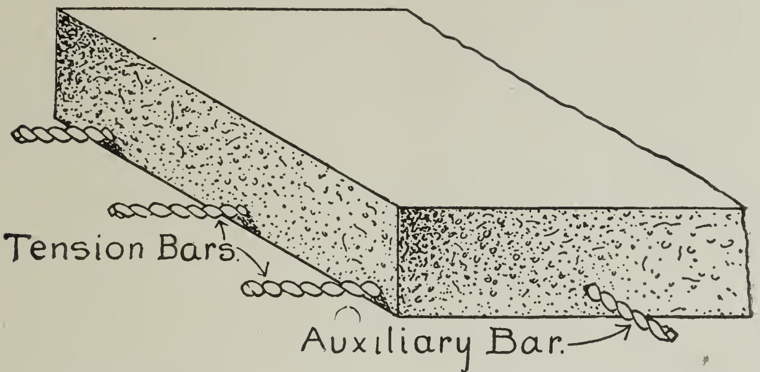

Fig. 487. Ransome Reinforced Concrete Floor. Early Flat Form.

Ransome system, using twisted iron rods imbedded in the concrete to give tensile strength where required.

The following description of this building, written some time ago

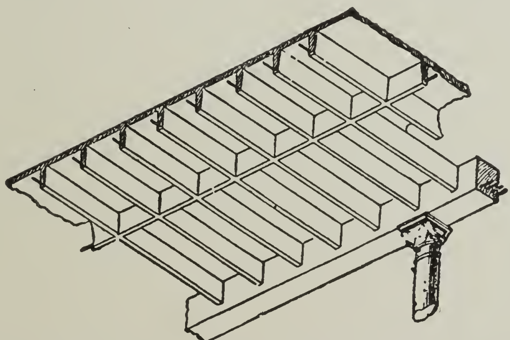

Fig. 488. Ransome Reinforced Concrete Floor. Early Panelled Form.

by the architect, Mr. Geo. W. Percy, gives an idea of the method of construction then employed and also of the cost in 1892, and is interesting for purposes of comparison with methods of construction used to-day.

"This building was designed to have dressed sandstone for the external walls, backed up with brick, and to have brick partitions with concrete floors. Owing to the great cost of stonework, it was decided to build the walls of cement concrete, colored to match the sandstone used in the other University buildings, and to carry out the classic design first adopted. This led to

making the entire structure, walls, partitions, floors, roof and dome of concrete, making it, in that respect, a unique building.

"Having some knowledge of the disadvantages and defects natural to a monolithic building, such as result from the shrinkage and the expansion and contraction of walls, floor and roof, several new experiments were tried to overcome them, with varying results of success and failure. It was thought to overcome the cracking of walls by inserting sheets of felting through the walls, following the lines of the joints as near as practicable on each side of the windows. The lapping bond of the concrete, however, proved too strong to allow the cracking to follow these joints; in most cases the weakest points were found at the openings, and small cracks appeared from window head to sills above.

"Joints were formed through the floors about 15 feet apart and in most cases the cracking followed these joints and was confined to them. To prevent the possibility of moisture penetrating through the walls, and also to render them less resonant, hollow spaces 5 inches in diameter were molded in the walls within 2 inches of the inside face, and with about 2 inches of concrete between them. These are successful for the primary object, and partially so for the secondary.

"The roof being the greatest innovation, and the first attempt known to the writer of forming a finished and exposed roof entirely in concrete, required the greatest care and consideration. The result in form and appearance is shown in Fig. 489, A and B, and may be described as follows: The roof is supported on iron trusses 10 feet on centers, and has a pitch of 20 degrees. The horizontal concrete beams rest on the iron rafters, and with the half arches form the horizontal lines of tiles about 2 feet 6 inches wide, with the joints lapping 2 inches and a strip of lead inserted as shown. Vertical joints are made through the concrete over each rafter with small channels on each side. These joints and channels are covered with the covering tiles shown on drawings, and similar rows of covering tiles are placed 2 feet 6 inches apart over the entire roof, thus forming a perfect representation of flat Grecian tile or marble roof. Notwithstanding the precautions taken, this roof presented several unexpected defects. The most serious proved to be in the Venetian red used for coloring matter and mixed with the cement. This material rendered the covering tiles absolutely worthless, many of them slacking like lumps of lime, and all were condemned and remade. The same material injured the general surface of the roof, rendering it porous and necessitating painting. The roof over the central pavilion being hidden behind parapets, is made quite flat and covered with asphaltum and gravel over the concrete. This roof, with its low, flat dome, is without question the largest horizontal span in concrete to be found anywhere on earth, being 46 feet by 56 feet, the flat dome having all its ribs and rings of concrete, with the panels or coffers filled with 1-inch thick glass and weighing about 80,000 pounds."

Fig. 490 shows an interior view of this dome and the hallway and corridors beneath. All the construction shown in this view is of

concrete. In the first story the walls are cased with marble slabs and above they are finished with plaster.

This Museum building, as well as the building of the California Academy of Science, withstood the shocks of the great earthquake remarkably well; and careful examinations showed that the former resisted the destructive tendencies better than did the two brick annexes adjoining It covers 21,000 feet and contains over 1,100,000 cubic feet of space. It required about 360,000 cubic feet of concrete, and was completed in seven months from the commencement of the foundations.

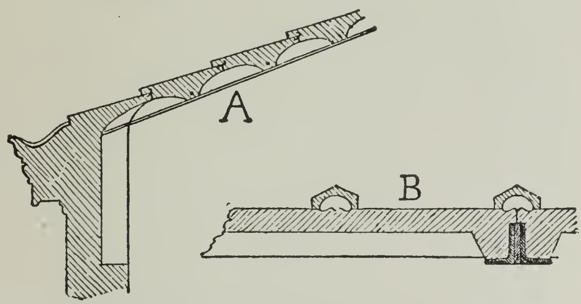

Fig. 489. Roof Construction of Dome Shown in Fig. 490.

The cost of the building per cubic foot, including marble stairs and wainscoting, cast-iron window frames and sashes and other parts to correspond, was about eighteen cents, which is a very low figure for a thoroughly substantial and fire-proof building.

Other important buildings which were executed in concrete about this time, or soon after, in the vicinity of San Francisco and built according to the Ransome system, were the Girls' Dormitory at the Leland Stanford Junior University (a three-story building completed in ninety days from the time the plans were ordered), the Science and Art building and Mills College; also the Torpedo Station on Goat Island, 80 by 250 feet, and an addition to the Borax Works at Alameda. In the latter the walls, interior columns and all floors were of concrete, and were said to be remarkable for lightness of construction and great strength.

The Alabama Apartments, Buffalo, N. Y.—Belonging to the early history of reinforced concrete hotels and apartment-houses in the United States may be mentioned the Alabama apartment-house, at Buffalo, N. Y., Mr. Carlton Strong, architect. This building is 60

by 180 feet in plan and six stories in height, with all walls, floors and partitions built of concrete, and it will be interesting and useful to present a few of the details of its construction, in order that any differences from those of similar buildings erected to-day may be observed.

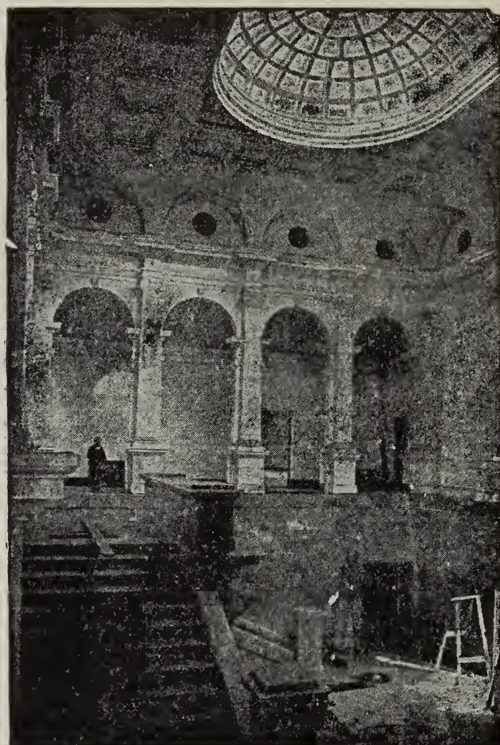

Fig. 490. Dome and Hallway of Leland Stanford Junior Museum, Palo Alto, Cal.

It was begun in 1894 and finished in 1896.

The general plan of the wall and floor construction is shown in Fig. 491, which represents a partial section at the level of the third floor

The whole thickness of the wall is 24 inches from top to bottom, the inner portion being 2 inches thick for the whole height. The outer portion is 8 inches thick in the first story, diminishing by 1 inch in each story.

Vertical twisted rods were built in the walls, as shown in the figure, and they were spaced about 15 feet apart, lengthwise of the

wall. Opposite these vertical rods the withes are 3 inches thick; elsewhere 1½ inches thick. In each withe were built ¼-inch twisted rods, extending across the wall and placed 12 inches apart vertically. At each floor level ¾-inch horizontal bars were imbedded in the walls as shown. These twisted steel bars tied the walls together in all directions, while the shape of the sections of the

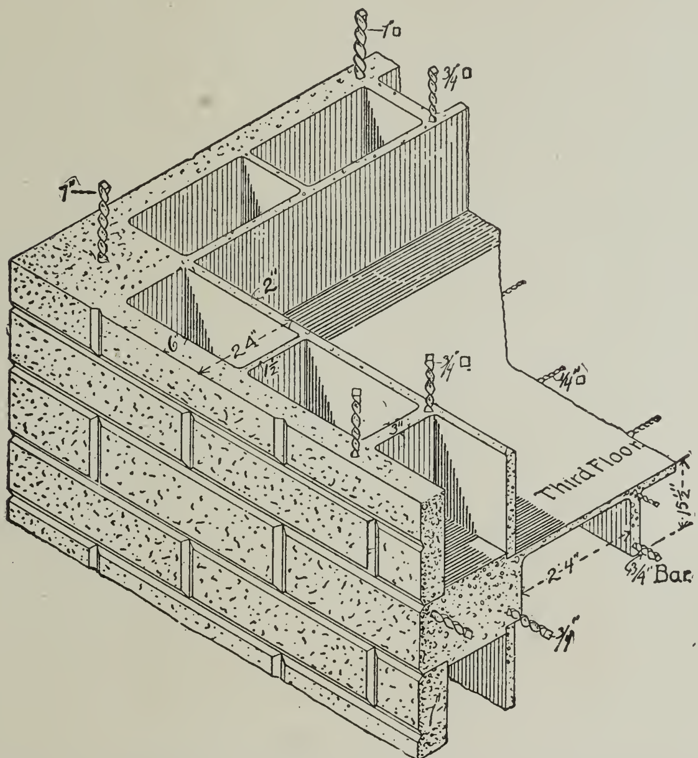

Fig. 491. Wall and Floor Construction, Alabama Apartment-house, Buffalo, N. Y.

wall gave the greatest stability with the least amount of material. The spaces in the walls were stopped at each floor level, except that for purposes of smoke flues or ventilation some of them were more or less continuous.

The floors were built according to the Ransome system, with concrete and twisted rods. Most of the floors were of the panelled construction shown in Fig. 488, although some portions were flat, and of the type shown in Fig. 487.

The partitions also were constructed of concrete, with twisted rods, and, being monolithic, added at the time greatly to the stiffness of the building.

Most of the concrete used was made in the proportions of 1 part of Portland cement to 6 parts of aggregate.

The contractors stated at the time that the average cost of the walls was twenty-five cents per square foot of outside surface.

Other Comparatively Early Examples of Reinforced Concrete Construction—The following is a partial list of some additional buildings of earlier date erected with walls, floors and partitions of reinforced concrete with the Ransome system of construction:

Fifteen-story office-building, Washington, D. C.
St. James' Church, Brooklyn, N. Y.
Willard Parker Hospital building, New York City.
Court-house and jail, Mineola, Long Island, N. Y.
Grandstand, Cincinnati, Ohio.
Six dry-kilns and two factories for the Singer Manufacturing Company, Cairo, Ill.
Twenty-four dry-kilns, pattern house and oil house, South Bend, Ind.
Four-story refineries for the Pacific Coast Borax Company, Bayonne, N. J.
Factory for the Farley Duplex Magnet Company, Jersey City, N. J.
Factory for the Central Lard Company, Jersey City, N. J.
Warehouse for the Pacific Coast Borax Company, Bayonne, N. J
Two 130-feet chimney stacks at South Bend, Ind., and one 100-feet stack at Jersey City, N. J.

The Ransome & Smith Company gave the cost of factory building construction between 1896 and 1900, under their system, at about 7 cents per cubic foot.

2. GENERAL THEORY AND DESIGN.

528. GENERAL CONSIDERATIONS.—With discussions on the theory of reinforced concrete design, the general theory of the flexure of beams, the theory of columns, and the mathematical derivations of various formulas, this book is not concerned, except in a very general way; and the reader is referred to the many excellent treatises and hand-books now available on these subjects.

As the subject of this work is "Building Construction," only those phases are discussed which relate especially to materials and construction. General and brief necessary references are made to the general principles of reinforced concrete design, and to those general principles of the mechanics of materials upon which this system of construction depends; but full mathematical and mechanical dis-

cussions are purposely omitted and only these general references included.

It has seemed desirable, however, in this connection, in this part of the chapter on a subject of such general importance and interest, to give some simple and approved working formulas for reinforced concrete beams, slabs and columns, with brief explanations and with the accompanying tables of constants, etc., necessary for their use.*

529. PROPERTIES OF THE MATERIALS.—Reinforced concrete is not a homogeneous material but a compound material, and a reinforced concrete beam is a compound beam. In a design where two or more materials, such, for example, as concrete and steel, are combined in the same member the stresses in the different materials depend not only upon the superimposed loads, but also upon the elastic properties of the materials. A knowledge of these elastic properties is therefore as necessary as a knowledge of those properties which relate to strength alone.

The concrete materials for concrete work in general have already been considered in general, as to their nature and strength, and also as to their elastic properties involving the modulus of elasticity and the elastic limit.

The reinforcing materials are considered further on.

530. STRESSES IN DIFFERENT KINDS OF REINFORCED CONCRETE STRUCTURAL MEMBERS.—For purposes of convenience structural members are usually classified as (1) Tension Members, (2) Compression Members and (3) Beams. This classification is based on the character of the forces resisted, and the stresses developed, namely, simple tension, simple compression and simple bending, respectively.

Tension or compression usually accompanies bending or flexure, and there are produced what are termed *combined stresses* of *bending and tension,* or of *bending and compression.*

Reinforced concrete is not employed for plain tension members.

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* In this instance the formulas and tables referred to are the same as used in Kidned's "Architect's and Builder's Pocket-Book" in Chapter XXIV, written by Mr. Rudolph P. Miller. The reader is referred to this chapter; and for fuller discussions of the mechanical side of building construction in general, to the remaining chapters of the "Pocket-Book."

It was always Mr. Kidder's desire that these two works of his should be complementary, and, as far as possible, used together, each supplementing the other; "Building Construction and Superintendence" dealing especially with materials and constructive methods and the "Architect's and Builder's Pocket-Book" dealing principally with calculations relating to the strength of materials, each, however, where convenience demands it, occasionally overlapping the other.

It is used for beams and girders, in which both plain bending and combined stresses may be studied; and for columns, which become compression members, but which may be investigated for flexure also. The flat reinforced concrete slab supported on four sides is usually considered as a special case of the beam.

531. NOTES ON THE FLEXURE OF BEAMS.—The external loads and reactions on a beam maintain their equilibrium by means of internal stresses which are generated in it. For any cross-section of a beam:

(1) The sum of the tensile stresses equals the sum of the compressive stresses.

(2) The resisting shear equals the vertical shear.

(3) The resisting moment equals the bending moment.

But these three important theoretical laws regarding internal stresses deduced from the three necessary conditions of static equilibrium are not alone sufficient for the full investigation of the subject of the flexure of beams, and recourse must be had to experience and experiment.

When a beam deflects one side becomes concave and the other convex, the approximately horizontal compression stresses being on the concave side and the tensile stresses on the convex side.

Fig. 492 shows a "simple beam" resting on two supports, loaded with a concentrated load L in the middle and in a state of flexure. The material of the beam near the upper surface will be in compression and that near the lower surface in tension, as indicated by the arrows.

Fig. 493 shows a "continuous beam," resting on and extending over the columns C and D and resting on the walls A and B. It is loaded with a concentrated load in the middle of the middle span, at L. The material of the beam will be in tension at P, in the lower part of the middle span and for a distance on each side of the middle, and will be in tension also in the upper part, over the two columns and for some distance on each side of them. These tensional stresses are indicated by the arrows at P, P_1 and P_2. Compressive stresses will be developed in the upper part of the beam in the middle of the middle span and in the lower part of the beam over and near the two columns.

In the simple beam in Fig. 492 the bending moment is greatest in the middle of the span, under the load, diminishing in value

toward the supports, where it becomes zero. The vertical shear is zero under the load and equal to each reaction between the load and either support. For unsymmetrical loads the greatest vertical shear is equal to the greater reaction and is at that support at which the greater reaction occurs.

In the continuous beam of Fig. 493 there is a maximum positive

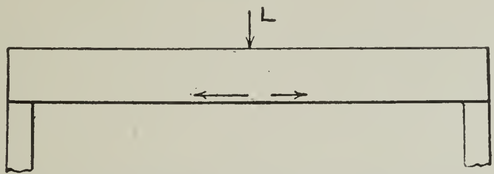

Fig. 492. Simple Beam. Load in Middle. Tensile Stresses in Lower Part.

bending moment in the middle of the middle span, under the load, and maximum negative bending moments over each column support, with shears at the supports as well as elsewhere.

Of course with variations in kinds of loading and in spans and with "restraint" at the walls, corresponding variations in reactions, moments and shears occur.

The "bending moment" for any cross-section of a beam is the algebraic sum of the moments of all the external forces on either side of the section. Those on the left of the section are usually taken.

The "vertical shear" for any cross-section is the name given to

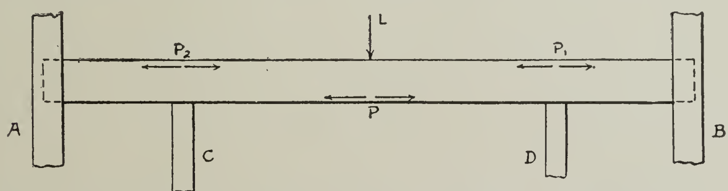

Fig. 493. Continuous Beam. Concentrated Load. Tensile and Compressive Stresses.

the algebraic sum of all the external forces on either side of the section. The forces on the left are usually taken.

The "resisting moment" is the algebraic sum of the moments of the internal horizontal stresses in any cross-section with reference to a point in that section.

The "resisting shear" is the algebraic sum of all the vertical components of the internal stresses in any cross-section of the beam.

It is found that any two vertical straight lines drawn on the side of a beam before flexure remain straight after flexure, but are nearer together than before on the compressive side and farther apart on the tensile side.

From the above data the following additional experimental laws have been added to the three theoretical laws already stated in the first part of this article:

(4) The horizontal fibers on the convex side are elongated and those on the concave side are shortened, while near the middle depth of the beam there is a "neutral surface" which is unchanged in length.

(5) The elongation or shortening of any fiber is directly proportional to its distance from the neutral surface.

(6) In beams of homogeneous material the horizontal stresses are directly proportional to their distances from the neutral surface, provided all unit-stresses are less than the elastic limit of the material.

From these laws is deduced the following important theorem:

(7) In beams of this kind the neutral surface passes through the centers of gravity of the cross-sections.

Fig. 494 shows the "lines of principal stress" in a beam in a state of flexure under loading. By combining the bending movement stresses with the shearing stresses at the various points of a beam, and plotting the results, curved lines of so-called "principal stress" are drawn as shown. In the middle of the span the stress lines are horizontal and at the ends vertical. Resolving these stress lines into their mechanical components, vertical and horizontal, as illustrated in Fig. 495 by the stepped lines at the section AA, it is seen that the horizontal component of each stress increases in magnitude as the middle of the span is approached, reaching a maximum at that point. The magnitude of each vertical component decreases toward the middle of the span and reaches its maximum at the end of the line of stress.

This figure is useful in designing reinforced concrete beams, and in locating the reinforcing metal in the proper places to resist the various stresses, and as far as possible to insure an equilibrium of horizontal and vertical forces and also of diagonal forces or of their horizontal and vertical components.

The above condensed notes are given in order to assist in a

clearer understanding of the terms used in working formulas, tables, and the demands of building laws relating to reinforced concrete construction.

532. NOTES ON REINFORCED CONCRETE BEAMS.— The object of reinforcement is apparent from the foregoing. Concrete being comparatively weak in tension and strong in com-

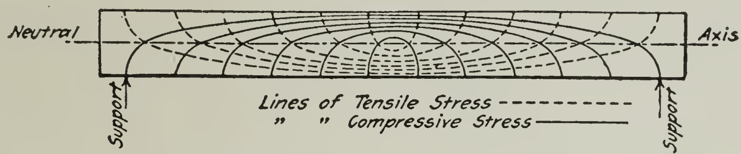

Fig. 494. Lines of Principal Stress in a Beam in a State of Flexure.

pression, if steel, which has a high tensional as well as compressive strength, is placed where tensional stresses are developed, if there is sufficient concrete properly placed to resist the compressive stresses, if the reinforcement is arranged generally to resist the shearing stresses, and if the compound structural member can be made to act as a unit, a strong and economical design will result.

Fig. 496 is an illustration of the simplest form of reinforcing for a simple beam in a state of flexure under a concentrated load in the middle of the span, and shows the effect of reinforcement in increasing the strength. These two 8 by 12-inch concrete beams were 12 feet long and were loaded as indicated until failure occurred.

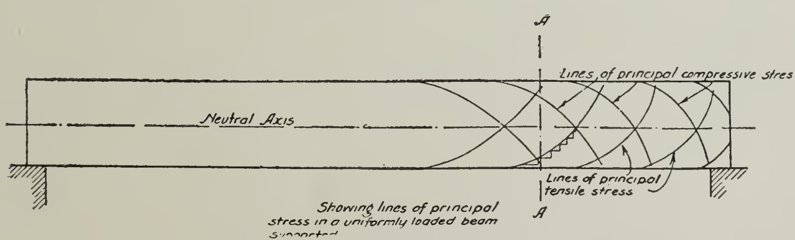

Fig. 495. Resolution of Principal Stress Lines in a Beam.

One beam was of plain concrete, without reinforcement; the other was reinforced as shown. The former failed with a load of 2,500 pounds, the latter did not fail until the loading reached 29,000 pounds, showing that the reinforcing rods had increased the strength over 11½ times.

Reinforcements in concrete beams vary from this simple form to more or less complicated arrangements of the metal; and while

details of procedure vary with different systems, the fundamental basis of all reinforced concrete design is the determination of the proper amount and arrangement of the metal necessary to resist the tensional stresses and of the concrete to resist the compressive stresses.

533. MANNER OF FAILURE OF REINFORCED CONCRETE BEAMS.—It is assumed that the concrete and steel adhere perfectly and deform equally. There may be simple adhesion, or a

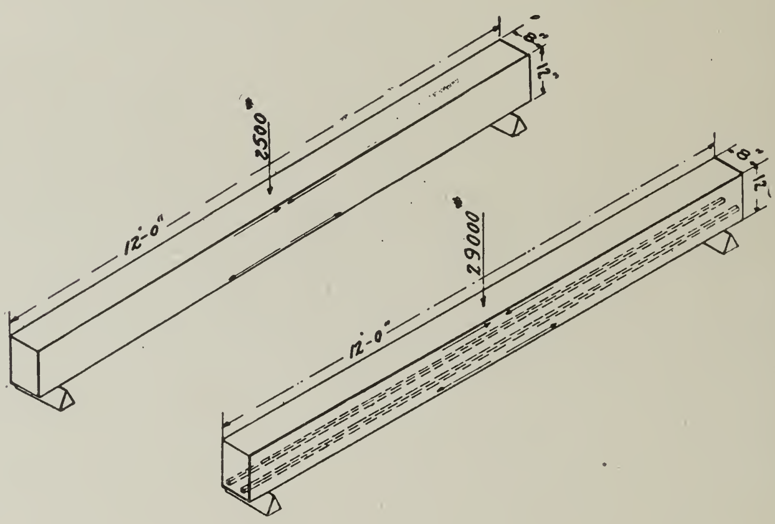

Fig. 496. Comparative Strength of Plain and Reinforced Concrete Beams.

grip from roughened or deformed bars, or an anchorage from a bending or anchoring at the ends.

"A reinforced concrete beam tested to destruction will usually fail in one of three ways:

(1) By the yielding of the steel at or near the section of maximum bending moment.

(2) By the crushing of the concrete at the same place.

(3) By a diagonal tension failure of the concrete at a place where the shear is large."*

There are also minor causes of failure, such as the slipping of the reinforcing rods, which is not likely to occur, and such as the shearing of the concrete near a support when the load is very close to it. This latter failure is also exceedingly unlikely to occur, as the

* "Principles of Reinforced Concrete Construction." Turneaure and Maurer.

shearing strength of concrete for true "vertical shear" is sometimes shown by tests to be nearly one-half its crushing strength.

The usual so-called "shearing" failures in a beam are in reality "diagonal-tension" failures, for which tensile strength values are used.

The following figures illustrate some of the ways in which reinforced concrete beams begin to fail when loaded to destruction:*

Fig. 497 shows a typical form of failure of a reinforced concrete beam due to diagonal tension.

Fig. 498 shows a typical form of failure caused by the splitting of the concrete above the reinforcement.

Fig. 499 shows a typical form of tension failure when the full proportion of the strength of both the concrete and the steel is developed, the diagonal-tensional stresses resisted, and the steel tending to fail by tensional stress. A reinforced concrete beam failing in this manner when tested to destruction indicates that the reinforcement is arranged in a more nearly effective manner than in the beams shown in the first two figures.

534. DESIGN OF REINFORCED RECTANGULAR BEAMS AND GIRDERS.—Different formulas have been proposed by investigators for the strength of reinforced concrete beams based on various theoretical considerations. The differences among them arise principally from three sources:

(1) The method of applying the factor of safety; some engineers assuming working strengths for the concrete and steel, with which, by a suitable flexure formula, the safe load is directly computed; and others computing the breaking load of the beam by a suitable formula and then deciding upon the safe load with reference to this breaking load.

(2) The law of distribution of the compressive fiber stress in the concrete. The most widely used flexure formulas for working conditions are based on the assumption that the stress-strain curve is practically straight up to working stresses. When the curvature of this curve is taken into account, it is generally assumed to be an arc of a parabola, some taking the vertex at the upper end of the curve, the ultimate strength end, and others taking it beyond that point.

* Reproduced from "Designing Tables." Courtesy of the Gabriel Concrete Reinforcement Company, Detroit, Mich.

(3) The value of the tensile fiber stress in the concrete. The residual tension in the concrete is seldom allowed for in the ultimate resisting moment in formulas, the almost universal practice being to neglect it entirely.

A dozen different diagrams may be drawn showing different dis-

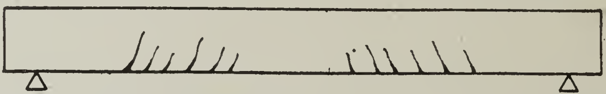

Fig. 497. Failure of Reinforced Concrete Beam by Diagonal Tension.

tributions of fiber stress in concrete according to various assumptions and also as many different formulas.*

The following formulas for the design of rectangular beams and girders of reinforced concrete give results closely approximating those from actual tests. They are simple in form and have been adopted in several building regulation codes in this country and abroad.

535. ASSUMPTIONS MADE IN FORMULAS USED.— The formulas used are based on the following assumptions:

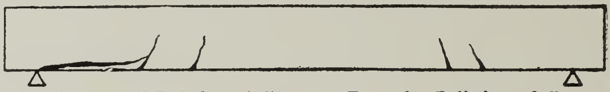

Fig. 498. Failure of Reinforced Concrete Beam by Splitting of Concrete.

(1) Sufficient bond between the concrete and steel to make them act together.

(2) A plane cross-section before flexure remains a plane after flexure and consequently the stress and strain (deformation) in any fiber are directly proportional to the distance of that fiber from the neutral axis of the cross-section.

(3) The modulus of elasticity of the concrete remains constant within the assumed working stresses.

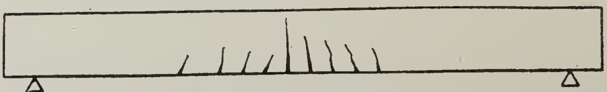

Fig. 499. Ideal Failure of Reinforced Concrete Beam by Steel Tension.

(4) The tensional stress is resisted entirely by the steel, the tensile strength of the concrete not being considered.

Fig. 500 shows a vertical longitudinal section of a reinforced

* See "Principles of Reinforced Concrete Construction," by Turneaure and Maurer, Chapter III, Article 52.

concrete beam in a state of flexure under a load. The vertical line in the middle is the trace or vertical section of a cross-section of the beam, and the horizontal broken line is the trace or vertical section of the neutral surface of the beam. The neutral axis of the cross-section of the beam is a vertical section of the neutral surface of the beam, or the line in which the neutral surface intersects the plane of the cross-section, and it appears in this drawing as the point of intersection of the vertical and horizontal lines referred to above. The position of the steel reinforcement is shown near the lower surface of the beam. The shaded triangle above the neutral surface line is the graphical representation of the variation of compressive stresses on a cross-section. The total compression on the cross-section is proportional to the area of the triangle, the

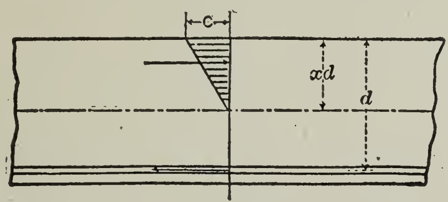

Fig. 500. Stress Diagram. Reinforced Concrete Beam.

average unit compressive fiber stress is represented by the average abscissa of the triangle and the resultant compression acts through the centroid of the triangle as shown by the horizontal arrow.

All the fibers above the neutral axis of the cross-section are in compression, and the resultant of the tensional stresses is at the center of gravity of the steel reinforcement.

By using these assumptions and conditions and the static and experimental laws stated in Article 531, the proper equations may be written and the formulas deduced.

536. FORMULAS FOR REINFORCED CONCRETE BEAMS.*—

S = the allowable tensile working unit-stress in the steel.

C = the allowable compressive working unit-stress in the extreme fiber of the concrete.

E_s = the modulus of elasticity of the steel.

E_c = the modulus of elasticity of the concrete in compression.

r = the ratio of the modulus of elasticity of the steel to the modulus of elasticity of the concrete, or $\frac{E_s}{E_c}$

* See footnote, Article 528.

d = the effective depth of the beam, that is, the distance from the center of gravity of the steel reinforcement to the extreme fiber in compression.

x = the ratio of depth of the neutral axis from the extreme fiber in compression to the effective depth of the beam, and is a number less than unity.

xd = the distance of the neutral axis from the extreme fiber in compression.

b = the width of the beam.

p = the ratio of cross-section of the steel to the cross-section of the beam, considering the beam all of that part of the concrete above the center of gravity of the steel.

M = the maximum bending moment which equals the resisting moment of the beam for the same section.

K = a factor used for simplification of the formula. This factor is constant for any given steel and concrete.

For beams of rectangular cross-section.

$$M = Kbd^2 \tag{10}$$

the value of K being determined by the following:

$$K = S\left(\frac{1}{\frac{2S}{C}\left(1+\frac{S}{Cr}\right)}\right)\left(1-\frac{1}{3\left(1+\frac{S}{Cr}\right)}\right) \tag{11}$$

which formula can be deduced from the laws of flexure and the assumptions noted above.

In the use of this formula for the value of K it must be remembered that the ratio of S to C, for any given ratio of steel to concrete, p, is a constant, so that corresponding values of S and C must be used. This ratio p, often spoken of as the "percentage of reinforcement," is the expression in the first parentheses,

$$p = \frac{1}{2\left(\frac{S}{C}\right)\left(1+\frac{S}{Cr}\right)} \tag{12}$$

The value of x is derived from the expression

$$x = rp\left(\sqrt{1+\frac{2}{rp}}-1\right) \tag{13}$$

Values for K and x for corresponding values of p, for different conditions fixed by the building authorities of different cities, are given in Tables XXXVIII and XXXIX.

TABLE XXXVIII.

Constants for Reinforced Concrete Beams When Ratio of Moduluses Is 12.

x = the coefficient, which, when multiplied by d, gives the position of the neutral axis.

K = the coefficient for determining the resisting moment in $M = Kbd^2$.

c = the extreme fiber stress in the concrete.

s = the extreme fiber stress in the steel.

$$For\ r = \frac{E_s}{E_c} = 12$$

p	x	K	C	S	K	C	S	K	C	S
.0005	.104	5.8	115	12000	6.8	135	14000	7.7	154	16000
.0010	.143	11.4	168	"	13.3	196	"	15.2	224	"
.0015	.172	17.0	209	"	19.8	244	"	22.6	279	"
.0020	.196	22.4	245	"	26.2	286	"	29.9	327	"
.0025	.217	27.8	276	"	32.5	323	"	37.1	369	"
.0030	.235	33.2	306	"	38.7	357	"	44.2	409	"
.0035	.251	38.5	335	"	44.9	390	"	51.3	446	"
.0040	.266	43.8	361	"	51.1	421	"	58.4	481	"
.0045	.279	49.0	387	"	57.1	452	"	63.3	500	15500
.0050	.291	54.2	412	"	63.2	481	"	65.7	"	14550
.0055	.303	59.3	436	"	68.1	500	13773	68.1	"	13773
.0060	.314	64.4	459	"	70.3	"	13083	70.3	"	13083
.0065	.325	69.6	480	"	72.5	"	12500	72.5	"	12500
.0070	.334	74.2	500	11929	74.2	"	11929	74.2	"	11929
.0075	.344	76.2	"	11467	76.2	"	11467	76.2	"	11467
.0080	.353	77.9	"	11030	77.9	"	11030	77.9	"	11030
.0085	.361	79.4	"	10618	79.4	"	10618	79.4	"	10618
.0090	.369	80.9	"	10250	80.9	"	10250	80.9	"	10250
.0095	.377	82.4	"	9921	82.4	"	9921	82.4	"	9921
.0100	.384	83.7	"	9600	83.7	"	9600	83.7	"	9600
.0105	.392	85.2	"	9333	85.2	"	9333	85.2	"	9333
.0110	.399	86.5	"	9068	86.5	"	9068	86.5	"	9068
.0115	.405	87.6	"	8804	87.6	"	8804	87.6	"	8804
.0120	.412	88.9	"	8583	88.9	"	8583	88.9	"	8583
.0125	.418	90.0	"	8360	90.0	"	8360	90.0	"	8360
.0130	.424	91.0	"	8154	91.0	"	8154	91.0	"	8154
.0135	.430	92.1	"	7963	92.1	"	7963	92.1	"	7963
.0140	.436	93.2	"	7786	93.2	"	7786	93.2	"	7786
.0145	.441	94.0	"	7603	94.0	"	7603	94.0	"	7603
.0150	.446	94.9	"	7433	94.9	"	7433	94.9	"	7433
.0155	.452	96.0	"	7290	96.0	"	7290	96.0	"	7290
.0160	.457	96.8	"	7141	96.8	"	7141	96.8	"	7141
.0165	.462	97.7	"	7000	97.7	"	7000	97.7	"	7000
.0170	.467	98.6	"	6868	98.6	"	6868	98.6	"	6868
.0175	.471	99.3	"	6729	99.3	"	6729	99.3	"	6729
.0180	.475	99.9	"	6597	99.9	"	6597	99.9	"	6597
.0185	.480	100.8	"	6486	100.8	"	6486	100.8	"	6486
.0190	.485	101.7	"	6382	101.7	"	6382	101.7	"	6382
.0195	.489	102.3	"	6269	102.3	"	6269	102.3	"	6269
.0200	.493	103.0	"	6163	103.0	"	6153	103.0	"	6163
.0005	.104	8.7	173	18000	9.7	192	20000	10.6	212	22000
.0010	.143	17.1	252	"	19.0	280		20.9	308	"
.0015	.172	25.4	314		28.3	349	"	31.1	384	"
.0020	.196	33.6	367	"	37.4	408	"	41.1	449	"
.0025	.217	41.8	415	"	46.4	461	"	50.3	500	21700
.0030	.235	49.8	460	"	54.2	500	19583	54.2	"	19583
.0035	.251	57.5	500	17929	57.5	"	17929	57.5	"	17929
.0040	.266	60.6	"	16625	60.6	"	16625	60.6	"	16625
.0045	.279	63.3	"	15500	63.3	"	15500	63.3	"	15500
.0050	.291	65.7	"	14550	65.7	"	14550	65.7	"	14550
.0055	.303	68.1	"	13773	68.1	"	13773	68.1	"	13773
.0060	.314	70.3	"	13083	70.3	"	13083	70.3	"	13083
.0065	.325	72.5	"	12500	72.5	"	12500	72.5	"	12500
.0070	.334	74.2	"	11929	74.2	"	11929	74.2	"	11929
.0075	.344	76.2	"	11467	76.2	"	11467	76.2	"	11467
.0080	.353	77.9	"	11030	77.9	"	11030	77.9	"	11030
.0085	.361	79.4	"	10618	79.4	"	10618	79.4	"	10618
.0090	.369	80.9	"	10250	80.9	"	10250	80.9	"	10250
.0095	.377	82.4	"	9921	82.4	"	9921	82.4	"	9921
.0100	.384	83.7	"	9600	83.7	"	9600	83.7	"	9600
.0105	.392	85.2	"	9333	85.2	"	9333	85.2	"	9333
.0110	.399	86.5	"	9068	86.5	"	9068	86.5	"	9068
.0115	.405	87.6	"	8804	87.6	"	8804	87.6	"	8804
.0120	.412	88.9	"	8583	88.9	"	8583	88.9	"	8583
.0125	.418	90.0	"	8360	90.0	"	8360	90.0	"	8360
.0130	.424	91.0	"	8154	91.0	"	8154	91.0	"	8154
.0135	.430	92.1	"	7963	92.1	"	7963	92.1	"	7963
.0140	.436	93.2	"	7786	93.2	"	7786	93.2	"	7786
.0145	.441	94.0	"	7603	94.0	"	7603	94.0	"	7603
.0150	.446	94.9	"	7433	94.9	"	7433	94.9	"	7433
.0155	.452	96.0	"	7290	96.0	"	7290	96.0	"	7290
.0160	.457	96.8	"	7141	96.8	"	7141	96.8	"	7141
.0165	.462	97.7	"	7000	97.7	"	7000	97.7	"	7000
.0170	.467	98.6	"	6868	98.6	"	6868	98.6	"	6868
.0175	.471	99.3	"	6729	99.3	"	6729	99.3	"	6729
.0180	.475	99.9	"	6597	99.9	"	6597	99.9	"	6597
.0185	.480	100.8	"	6486	100.8	"	6486	100.8	"	6486
.0190	.485	101.7	"	6382	101.7	"	6382	101.7	"	6382
.0195	.489	102.3	"	6269	102.3	"	6269	102.3	"	6269
.0200	.493	103.0	"	6163	103.0	"	6163	103.0	"	6163

TABLE XXXIX.

CONSTANTS FOR REINFORCED CONCRETE BEAMS WHEN RATIO OF MODULUSES IS 15.

$$\textit{For } r = \frac{E_s}{E_c} = 15$$

p	x	K	C	S	K	C	S	K	C	S
.0005	.115	5.8	104	12000	6.7	122	14000	7.7	139	16000
.0010	.159	11.4	151	"	13.3	176	"	15.2	201	"
.0015	.191	16.9	188	"	19.7	220	"	22.5	251	"
.0020	.217	22.3	221	"	26.0	258	"	29.7	295	"
.0025	.239	27.6	251	"	32.2	293	"	36.8	335	"
.0030	.258	32.9	279	"	38.4	326	"	43.9	372	"
.0035	.276	38.1	304	"	44.5	355	"	50.9	406	"
.0040	.292	43.3	329	"	50.6	384	"	57.8	438	"
.0045	.306	48.5	353	"	56.6	412	"	64.7	471	"
.0050	.320	53.6	375	"	62.6	438	"	71.5	500	"
.0055	.332	58.7	398	"	68.5	464	"	73.8	"	15091
.0060	.344	63.8	419	"	74.4	488	"	76.2	"	14333
.0065	.355	68.8	439	"	78.3	500	13654	78.3	"	13654
.0070	.365	73.8	460	"	80.1	"	13036	80.1	"	13036
.0075	.375	78.8	480	"	82.0	"	12500	82.0	"	12500
.0080	.384	83.7	500	"	83.7	"	12000	83.7	"	12000
.0085	.393	85.4	"	11559	85.4	"	11559	85.4	"	11559
.0090	.402	87.0	"	11167	87.0	"	11167	87.0	"	11167
.0095	.410	88.5	"	10789	88.5	"	10789	88.5	"	10789
.0100	.418	89.9	"	10450	89.9	"	10450	89.9	"	10450
.0105	.425	91.2	"	10119	91.2	"	10119	91.2	"	10119
.0110	.433	92.6	"	9841	92.6	"	9841	92.6	"	9841
.0115	.440	93.9	"	9565	93.9	"	9565	93.9	"	9565
.0120	.446	94.9	"	9292	94.9	"	9292	94.9	"	9292
.0125	.453	96.2	"	9060	96.2	"	9060	96.2	"	9060
.0130	.459	97.2	"	8827	97.2	"	8827	97.2	"	8827
.0135	.465	98.2	"	8611	98.2	"	8611	98.2	"	8611
.0140	.471	99.3	"	8411	99.3	"	8411	99.3	"	8411
.0145	.477	100.3	"	8224	100.3	"	8224	100.3	"	8224
.0150	.483	101.3	"	8050	101.3	"	8050	101.3	"	8050
.0155	.488	102.2	"	7871	102.2	"	7871	102.2	"	7871
.0160	.493	103.0	"	7703	103.0	"	7703	103.0	"	7703
.0165	.498	103.8	"	7545	103.8	"	7545	103.8	"	7545
.0170	.503	104.6	"	7397	104.6	"	7397	104.6	"	7397
.0175	.508	105.5	"	7257	105.5	"	7257	105.5	"	7257
.0180	.513	106.3	"	7125	106.3	"	7125	106.3	"	7125
.0185	.518	107.2	"	7000	107.2	"	7000	107.2	"	7000
.0190	.522	107.8	"	6868	107.8	"	6868	107.8	"	6868
.0195	.527	108.6	"	6756	108.6	"	6756	108.6	"	6756
.0200	.531	109.3	"	6638	109.3	"	6638	109.3	"	6638
.0005	.115	8.7	157	18000	9.6	174	20000	10.6	191	22000
.0010	.159	17.1	226	"	18.9	252	"	20.8	277	"
.0015	.191	25.3	283	"	28.1	314	"	30.9	346	"
.0020	.217	33.4	332	"	37.1	369	"	40.8	406	"
.0025	.239	41.4	377	"	46.0	418	"	50.6	460	"
.0030	.258	49.3	419	"	54.8	465	"	58.9	500	21500
.0035	.276	57.2	457	"	62.7	500	19714	62.7	"	19714
.0040	.292	64.0	493	"	65.9	"	18250	65.9	"	18250
.0045	.306	68.7	500	17000	68.7	"	17000	68.7	"	17000
.0050	.320	71.5	"	16000	71.5	"	16000	71.5	"	16000
.0055	.332	73.8	"	15091	73.8	"	15091	73.8	"	15091
.0060	.344	76.2	"	14333	76.2	"	14333	76.2	"	14333
.0065	.355	78.3	"	13654	78.3	"	13654	78.3	"	13654
.0070	.365	80.1	"	13036	80.1	"	13036	80.1	"	13036
.0075	.375	82.0	"	12500	82.0	"	12500	82.0	"	12500
.0080	.384	83.7	"	12000	83.7	"	12000	83.7	"	12000
.0085	.393	85.4	"	11559	85.4	"	11559	85.4	"	11559
.0090	.402	87.0	"	11167	87.0	"	11167	87.0	"	11167
.0095	.410	88.5	"	10789	88.5	"	10789	88.5	"	10789
.0100	.418	89.9	"	10450	89.9	"	10450	89.9	"	10450

TABLE XXXIX.—*Continued.*

CONSTANTS FOR REINFORCED CONCRETE BEAMS WHEN RATIO OF MODULUSES IS 15.

p	x	K	C	S	K	C	S	K	C	S
.0105	.425	91.2	500	10119	91.2	500	10119	91.2	500	10119
.0110	.433	92.6	"	9841	92.6	"	9841	92.6	"	9841
.0115	.440	93.9	"	9565	93.9	"	9565	93.9	"	9565
.0120	.446	94.9	"	9292	94.9	"	9292	94.9	"	9292
.0125	.453	96.2	"	9060	96.2	"	9060	96.2	"	9060
.0130	.459	97.2	"	8827	97.2	"	8827	97.2	"	8827
.0135	.465	98.2	"	8611	98.2	"	8611	98.2	"	8611
.0140	.471	99.3	"	8411	99.3	"	8411	99.3	"	8411
.0145	.477	100.3	"	8224	100.3	"	8224	100.3	"	8224
.0150	.483	101.3	"	8050	101.3	"	8050	101.3	"	8050
.0155	.488	102.2	"	7871	102.2	"	7871	102.2	"	7871
.0160	.493	103.0	"	7703	103.0	"	7703	103.0	"	7703
.0165	.498	103.8	"	7545	103.8	"	7545	103.8	"	7545
.0170	.503	104.6	"	7397	104.6	"	7397	104.6	"	7397
.0175	.508	105.5	"	7257	105.5	"	7257	105.5	"	7257
.0180	.513	106.3	"	7125	106.3	"	7125	106.3	"	7125
.0185	.518	107.2	"	7000	107.2	"	7000	107.2	"	7000
.0190	.522	107.8	"	6868	107.8	"	6868	107.8	"	6868
.0195	.527	108.6	"	6756	108.6	"	6756	108.6	"	6756
.0200	.531	109.3	"	6638	109.3	"	6638	109.3	"	6638

(For Table XL see next page.)

537. DETERMINATION OF THE SIZE OF RECTANGULAR REINFORCED CONCRETE BEAMS.—To determine the size of a beam required for any particular case, formula (10) is put into the form

$$d=\sqrt{\frac{M}{Kb}} \qquad (14)$$

The breadth b is assumed, M is the maximum bending moment at the dangerous section, r, C and S are given and K is found either by using formula (11) or from Tables XXXVIII and XXXIX. The equation is then solved for the depth d.

As there are numerous correct solutions for varying ratios of d and b, it frequently happens in practice that several trials have to be made to satisfy some particular structural or architectural requirements.

538. DETERMINATION OF THE STRENGTH OR DIMENSIONS OF REINFORCED CONCRETE SLABS.—The formulas given for beams may be used to determine the strength or dimensions of slabs. Any one of three treatments may be employed:

(1) Slab considered a very wide rectangular beam.

(2) Slab considered a series of beams, side by side, each beam having one reinforcing rod and a width equal to the distance on centers of the rods.

(3) Slab considered a series of beams, side by side, each beam having a unit-width and a unit-area of reinforcement.

In the following table the values of K and of the other constants are given for cinder concrete. This table should be used only for slabs between floor beams, as cinder concrete, while possessing excellent fire-resisting properties, is weak when compared with the stone and gravel mixtures.

XL.

Constants for Reinforced Cinder Concrete Slabs. Ratio of Moduluses, 35.

For $r = \frac{E_s}{E_c} = 35$

p	x	K	C	S	K	C	S
.0005	.170	7.5	94	16000	7.5	94	16000
.0010	.232	14.8	138	"	14.8	138	16000
.0015	.276	21.8	174	"	18.8	150	13800
.0020	.311	28.7	206	"	20.9	"	11633
.0025	.340	33.9	225	15300	22.6	"	10200
.0030	.365	36.1	"	13688	24.0	"	9125
.0035	.387	37.9	"	12439	25.3	"	8293
.0040	.407	39.6	"	11447	26.4	"	7631
.0045	.425	41.0	"	10625	27.4	"	7083
.0050	.442	42.4	"	9945	28.3	"	6630
.0055	.457	43.6	"	9348	29.1	"	6232
.0060	.471	44.7	"	8831	29.8	"	5888
.0065	.484	45.7	"	8377	30.4	"	5585
.0070	.497	46.7	"	7988	31.1	"	5325
.0075	.508	47.5	"	7620	31.6	"	5080
.0080	.519	48.3	"	7298	32.2	"	4866
.0085	.529	49.0	"	7001	32.7	"	4668
.0090	.539	49.7	"	6738	33.2	"	4492
.0095	.548	50.4	"	6489	33.6	"	4326
.0100	.557	51.0	"	6266	34.0	"	4178
.0105	.565	51.6	"	6054	34.4	"	4036
.0110	.573	52.1	"	5860	34.8	"	3907
.0115	.581	52.7	"	5684	35.1	"	3789
.0120	.588	53.2	"	5513	35.5	"	3675
.0125	.595	53.7	"	5355	35.8	"	3570
.0130	.602	54.1	"	5210	36.1	"	3473
.0135	.608	54.5	"	5067	36.4	"	3378
.0140	.615	55.0	"	4942	36.7	"	3295
.0145	.621	55.4	"	4818	36.9	"	3212
.0150	.626	55.7	"	4695	37.1	"	3130
.0155	.632	56.1	"	4587	37.4	"	3058
.0160	.637	56.4	"	4479	37.6	"	2986
.0165	.643	56.8	"	4384	37.9	"	2923
.0170	.648	57.2	"	4288	38.1	"	2859
.0175	.652	57.4	"	4191	38.3	"	2794
.0180	.657	57.7	"	4106	38.5	"	2738
.0185	.662	58.1	"	4026	38.7	"	2684
.0190	.666	58.3	"	3943	38.9	"	2629
.0195	.671	58.6	"	3871	39.1	"	2581
.0200	.675	58.9	"	3797	39.2	"	2531

539. CONVENIENT CHECK-FORMULAS FOR REINFORCED CONCRETE RECTANGULAR BEAM CONSTRUCTION.—Formulas may be used to test reinforced concrete beam calculations and construction.

When it is desired to find the safe loading for a given beam the following formulas may be used:

$$M = p\,S\,b\,d^2\left(1-\frac{x}{3}\right) \qquad (15)$$

$$M = \frac{C\,x\,b\,d^2}{2}\left(1-\frac{x}{3}\right) \qquad (16)$$

The assumed working stresses S and C are substituted in these formulas, and if the resulting values for M are unequal the smaller of the two values is taken for the proper value of the maximum bending moment. Resulting inequality of values for M indicates a non-economical proportion or arrangement of the two materials employed and a failure to obtain the full resistance of one or the other.

When it is desired to investigate a given beam, that is, to find the stresses S and C, for a given loading, the following forms of the same formulas may be used:

$$S = \frac{M}{p\,b\,d^2\left(1-\frac{x}{3}\right)} \qquad (17)$$

$$C = \frac{2\,M}{x\,b\,d^2\left(1-\frac{x}{3}\right)} \qquad (18)$$

In formulas (15) and (16) x is found from the tables given, and in formulas (17) and (18) it is determined by formula (13).

In formula (17) the denominator of the second member of the equation is a transformed expression for the product of the area of the cross-section of the reinforcement by the distance of its center of gravity from the center of compression of the concrete; and in formula (18) the denominator of the second member of the equation is an expression for the product of the area of the cross-section of the concrete in compression by the same distance.

540. GENERAL PRINCIPLES OF REINFORCED CONCRETE T-BEAM DESIGN.—Fig. 501 is a cross-section of a reinforced concrete T-beam formed by using a portion of the

floor slabs and a rectangular beam together as one beam of T-shape. The neutral axis of the cross-section is shown and also the reinforcing rods near the lower surface of the stem or web part.

b' = the width of the slab part taken.

h' = the depth of the slab.

b = the width of the stem.

d, x and xd, and the other terms of the formulas have the same meanings as in Articles 536 and 537, in the formulas for rectangular beams.

Floor slabs are commonly used in connection with beams and girders, and an economical design results when they are cast as

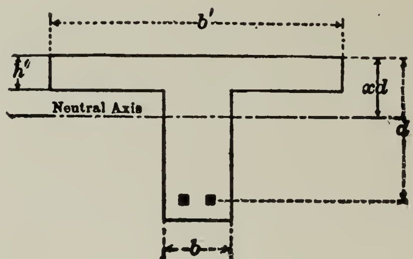

Fig. 501. Cross-section Reinforced Concrete T-beam.

units and considered together, as the slabs add much to the strength of the beams or girders.

Practice and building regulations differ in regard to the width of the slab to be considered as part of the beam. The New York building laws give "ten times the width of the beam or girder," or the stem of the T-beam. Other regulations give as a maximum width for the flange one-third the span of the beam.

It is generally convenient to first determine the necessary thickness of the floor slabs required for any particular case of beam spacing, taking this thickness for that of the T-beams.

When such T-beams frame into reinforced concrete girders, these girders also may be designed as T-girders, with slab flanges of the same thickness as is used for the beam slabs; and the same slab, or as much of it as is required, may be used for both beam and girder when they come together. Both have compressive stresses and some authorities claim that they assist each other; while

others endeavor to avoid "an integration of compressive stresses due to simultaneous action as floor slab and girder flange."*

541. FORMULAS FOR REINFORCED CONCRETE T-BEAMS.—For these beams there may be considered any one of three positions of the neutral axis:

(1) The neutral axis of the cross-section may be below the flange.

(2) The neutral axis may be in the plane of the under surface of the flange.

(3) The neutral axis may be above the under surface of the flange.

In the first case

$$M = S\,p\,b\,d\left(d - \frac{h'}{2}\right) \tag{19}$$

$$M = \frac{C}{2}\,b'\,h'\left(d - \frac{h'}{2}\right) \tag{20}$$

To simplify the formulas, the center of compression in the concrete is taken at the middle of the thickness of the flange, and the small proportion of concrete in compression below the flange and above the neutral axis is neglected.

The position of the neutral axis may be found by the formula

$$x = \frac{2\,b\,d^2\,p\,r + b'\,h'^2}{2d\,(b\,d\,p\,r + b'\,h')} \tag{21}$$

The most economical percentage of reinforcement may be found by the formula

$$p = \frac{C\,b'\,h'}{2\,S\,b\,d} \tag{22}$$

In this formula the area *bd*, only, of the concrete is taken and the remainder of the concrete cross-section area neglected.

In the second case the formulas for the values of M and of p are the same as for the first case, and h' becomes xd.

In the third case the treatment is the same as in the second case because the flange concrete below the neutral axis is neglected. Thus, in this case also, h' becomes xd.

542. WORKING UNIT-STRESSES IN REINFORCED CONCRETE DESIGN.—Some working stresses for mass concrete and also for reinforced concrete construction have been given in Article 503. The allowable working stresses for concrete and steel in several cities is given in the following table:

* "Building Laws and Ordinances," Philadelphia.

TABLE XLI.

Working Unit-stresses for Reinforced Concrete Design.

City or Authority	Extreme Fiber Stress in Comp. in Concrete Per Square Inch C	Diagonal Tension Stress in Concrete Per Square Inch	Direct Comp. in Concrete Per Square Inch	Adhesion of Steel to Concrete Per Square Inch	Tensile Stress in Steel Per Square Inch S	Shearing Stress in Steel Per Square Inch	Ratio of Modulus of Steel to Modulus of Concrete (r)
New York	500	50	350	50	16000	10000	12
Chicago	500	75	350	75⅛	⅓Elastic Limit	10000	12
Philadelphia	600	75	500 Col's.	50	16000	.....	12
St. Louis	500	50	350	50	.....	.....	18
Boston	500	60	416 Mx 347 Mn	..	.....	.....	15 in Beams and Slabs and 10 in Col's
Cleveland	500	50	350	50	16000	10000	15
Buffalo	500	50	350	50	16000	10000	12
San Francisco	500	75	450	75	⅓Elastic Limit	10000	15
National Board of Fire Underwriters	500	50	350	50	.....	.....	18

The stresses are for "medium steel." The working stresses in the steel should be a fixed proportion of either the yield point or of the elastic limit. The working unit tensile stress for "high carbon steel" is ordinarily taken as 20,000 pounds per square inch.

The values of $r = \frac{E_s}{E_c}$, C and S, given in the table above, are used in determining the value of K in the formula (11) of Article 536, when the value of K is not taken directly from Tables XXXVIII and XXXIX.

543. MODULUSES OF ELASTICITY OF STEEL AND CONCRETE IN REINFORCED CONCRETE DESIGN.—In order to know the value of the $r = \frac{E_s}{E_c}$ of the formulas and tables, it is necessary to know the values of E_s, the modulus of elasticity of steel and of E_c, the modulus of elasticity of concrete.

The average of the former is, for practical work, generally accepted as about 30,000,000 pounds per square inch, and of the latter as about 2,500,000 pounds per square inch.

These values, of course, are averages, and there are great variations, especially for concrete, the value of E_c varying with many conditions, such as the character of materials, the manner of mixing

and placing, the age of the concrete, the richness of the mixture, the amount of load on the concrete, etc.

544. BENDING MOMENTS IN REINFORCED CONCRETE BEAM DESIGN.—The correct values of M, the maximum bending moment of the external forces acting on a reinforced concrete beam or slab, have to be found. The values are deter-

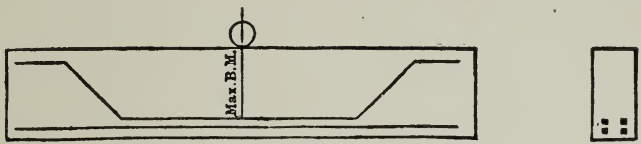

Fig. 502. Bending Moment Diagram. Uniformly Distributed Load.

mined by theoretical considerations of the laws of flexure or fixed by the requirements of building laws.

Figs. 502 and 503 are simple diagrams illustrating in a very general way the average usual disposition of reinforcements in beams, with reference to the kind of loading, the supports, the positions of the positive and negative bending moments, etc.

In continuous beams there are positive bending moments between the supports and negative bending moments over the supports. Reinforcements in the upper part of a continuous beam should be provided for the latter. In simple beams the bending moment

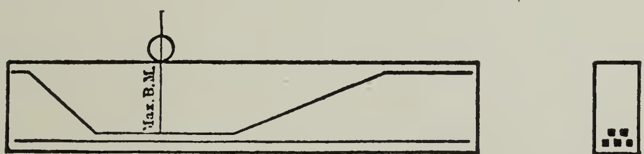

Fig. 503. Bending Moment Diagram. Concentrated or Unsymmetrical Load.

decreases toward the supports. Accordingly, the steel reinforcing rods should be disposed in sets or pairs to resist the tensional stresses, some of them running up toward the upper parts of the beam as they approach the supports and there carried across if the beams are continuous.

Fig. 502 shows the position of the maximum positive bending moment and the general arrangement of reinforcement for a uniformly distributed or symmetrical load, and Fig. 503 for a concentrated or unsymmetrical load.

The calculations involved in designing continuous beams are

relatively complicated, and reinforced concrete beams are usually treated as "simple beams," that is, as beams supported at the ends and *not* continuous. The difference in the results of the calculations is on the side of safety. The building laws of the following, among other large cities, require that beams and girders shall be considered as simply resting on two supports: New York, Chicago, Philadelphia, Cleveland, San Francisco, Buffalo and St. Louis.

545. BENDING MOMENTS IN REINFORCED CONCRETE SLAB DESIGN.—Floor slabs are usually carried continuously across supports over wide areas, and bending moments due to uniformly distributed loads are considered to be less in magnitude than in beams resting on two supports.

The following are the Philadelphia building laws for reinforced concrete floor slabs:

"Floor slabs, when constructed continuously, and when provided with reinforcement at top of a slab over the supports, may be treated as continuous beams, the bending moment for uniformly distributed loads being taken at not less than $\frac{Wl}{10}$. In case of square floor slabs which are reinforced in both directions and supported on all sides, the bending moment may be taken at $\frac{Wl}{20}$, provided that in floor slabs in juxtaposition to the walls of the building the bending moment shall be considered as $\frac{Wl}{8}$ when reinforced in one direction; and if the floor slabs are square and reinforced in both directions, the bending moment shall be taken as $\frac{Wl}{16}$."

In the above, W is the total load on a slab in pounds, and l the span in inches, the resulting bending moment being in inch-pounds.

The following is a formula proposed by Professor C. Bach for the bending moment of slabs supported on four sides and reinforced in both directions:

$$M = \frac{1}{12} \frac{a^2 \times b^2}{\sqrt{a^2 + b^2}} p \qquad (23)$$

M = maximum bending moment in inch-pounds for a uniformly distributed load.

a = the length of the slab in inches.

b = the width of the slab in inches.

p = the load on the slab per square inch.

546. AMOUNT OF REINFORCEMENT AND ITS DISPOSITION IN CONCRETE BEAMS.—Figs. 502 and 503 show some general arrangements and numbers of rods. At the beam

sections of maximum bending moment full sectional areas of reinforcement must be provided, and throughout the beam these areas must be sufficient to resist the tensional stresses below the neutral axis. The turning up of some of the rods must be done at the proper places, depending upon the character of the loading.

An even number of rods is better adapted to a symmetrical arrangement in cross-section and longitudinal section, in regard to the grouping at and near the point of maximum bending moment and to the turning up toward the supports. Too great a number of rods is undesirable, but a larger number of smaller rods is preferable to a smaller number of larger rods, as the areas of contact for cylindrical rods decrease as the diameters of their circular cross-section, while the volumes of the rods decrease as the squares of the diameters.

Whatever the arrangement, the rods must be satisfactorily incased in the concrete. Partly, if not entirely, on account of an insufficiency of concrete between and around the rods, the concrete sometimes splits off along the line of reinforcement at the under side of beams during tests. This result is avoided by spacing the rods in the cross-sections so that the resistance of the concrete to shear at the level of the rods is at least equal to the adhesion of the concrete to the steel.

If the safe values for adhesion and shear are taken about equal, the rods should be spaced 2½ diameters on centers and 2 diameters from the sides of the beams. Authorities do not agree yet on this point, some,* for example, naming 1½ inches as a minimum and others† naming 1½ inches as a sufficient maximum distance.

The percentage of reinforcement for rectangular and T-beams is found as explained in Articles 536 and 541 by the formulas (12) and (22). The amount may vary from one-fourth of one per cent to one and one-half per cent of the concrete area. A usual average is about seven-tenths of one per cent.

After deciding upon the number of rods required, the size of each one can be found and the rods selected from tables, manufacturers' catalogues, etc.

547. BREADTH OF REINFORCED CONCRETE BEAMS. —In Article 537, in using the formula to determine the size of rec-

* "Concrete, Plain and Reinforced." Taylor & Thompson.
† Brooklyn, N. Y., Regulations for Reinforced Concrete Construction.

tangular beams, the breadth of the beam is assumed. The breadth may be said to depend generally upon the necessary reinforcement, and upon the safe ratio of the least side-dimension of cross-section to the length of the beam, considered as a column in compression above the neutral axis. In regard to the amount of reinforcement, the necessary width equals the sum of the diameters of the tension rods, the spaces between them and the amount of concrete outside them necessary to resist shear and to protect the metal; and when stirrups are omitted the width of concrete must be sufficient to resist the horizontal shear, a width which should be at least equal to the sum of the perimeters of the cross-sections of the tensional reinforcing rods.

The breadth is often assumed equal to from 1/24 to 1/20 of the span. The best-shaped beam is usually one in which the breadth lies between ½ and ¾ of the depth.

The thickness of the concrete below the rods is determined by the requirements of fire-protection and corrosion-resistance. The thickness varies from 1 to 2 inches, according to conditions.

548. DIAGONAL TENSION IN REINFORCED CONCRETE BEAM DESIGN.—In Article 503 the average safe unit-value for the "vertical shear" for concrete is given, and in Article 531 this unit stress is defined. What is often termed "shear" in a reinforced concrete beam is really *diagonal tension.* There is a tendency to shear horizontally at the neutral surface of a beam, and this tendency diminishes toward the top and bottom of a beam. The diagonal tension in this case should not exceed from 50 to 75 pounds per square inch, and is taken in building laws at from 50 to 75 pounds per square inch. It will be noticed that this value is just about the allowable adhesive and tensional stress of the concrete.

To resist these diagonal tension stresses in the concrete, metal "stirrups" are provided and fastened in some way to the lower rods. The exact amount and position of such stirrups for any particular case of reinforcement are not definitely agreed upon by different authorities, some claiming that they should be vertical, others that they should be inclined. The stirrups are generally firmly attached to the tensional reinforcement, although some claim that this is not necessary. Different kinds of stirrups are shown in the different types of reinforcements and construction.

The size and spacing of stirrups may be determined by formulas given in hand-books on the subject.*

549. COMPRESSION RODS IN REINFORCED CONCRETE BEAMS.—The use of steel in compression in concrete beams is not generally recommended, since it is more economical to carry compressive stresses by the concrete than by the steel. Limitations as to size, however, and the occasional desirability of providing additional compressive strength where there is not sufficient concrete above the neutral axis to resist the total compression, leads to the introduction of a double reinforcement in the shape of rods in the upper portion of the beams.

Steel reinforcement in the compressive side has little effect in beams that would otherwise fail in tension or shear, the only gain being that due to an increased distance between centers of resultant tensile and compressive forces. Tests made on doubly reinforced beams show that the steel in compression takes its share of stress, and that the compressive side of the beam is strengthened in accordance with the usual theory. Steel with a fairly high elastic limit should be used in order to obtain its full benefit up to the point of rupture.

The steel should be placed as high as possible. The usual rule is to limit the allowable unit-compression in the steel to the actual compression in the concrete at that point multiplied by the ratio of the modulus of elasticity of the steel to that of the concrete, as in the case of columns with vertical reinforcement.

550. ADHESION OF THE CONCRETE TO THE REINFORCEMENT.—In a reinforced concrete beam in a state of flexure under a load there is a tendency for the concrete to shear horizontally along the reinforcement. This is resisted in part by the adhesion between the steel and the concrete. With plain round or square rods the adhesion between the two materials furnishes the only bond, but various commercial types of bars are in use, provided with projections or indentations of different shapes to prevent slipping. Either a so-called "mechanical bond" is formed or the reinforcements are anchored at the ends.

Many tests have been made to determine the force necessary to pull bars of different cross-sections from the concrete, and to determine the adhesion between the materials.

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* See the "Architect's and Builder's Pocket-Book," Frank E. Kidder, Chapter XXIV, and *Engineering News*, April 16, 1903, p. 348.

The results of some valuable pulling-out tests made by Professor Edgar Marburg, of the University of Pennsylvania, are given in the following table.* In these tests the rods were centrally imbedded in 6-inch by 6-inch concrete prisms 12 inches long and were tested after thirty days.

The plain rods generally pulled out, but in most of the cases of the other rods failure was due to the breaking of the rods or to the cracking of the concrete.

TABLE XLII.

PULLING-OUT TESTS FOR DIFFERENT REINFORCING RODS.

Kind of Rod	Total Load, Pounds	Load Per Linear Inch of Rod, Pounds	Remarks
Johnson	13660	1138	Elastic limit passed. Concrete cracked
	12830	1069	Elastic limit passed. Concrete cracked
	9980	832	Concrete cracked
Plain	6280	524	Rod pulled out
	6190	516	Rod pulled out
	5650	471	Rod pulled out
Thacher	10420	868	Rod broke
	8890	741	Concrete cracked
	9970	831	Rod broke
Ransome	22690	1891	Concrete cracked
	16680	1390	Concrete cracked
	19290	1608	Rod pulled out

In a beam conditions are more favorable than in tests conducted by either a method of pulling out or one of pushing out, as in a beam both the steel and the concrete are elongated and the stress has thus a tendency to distribute itself more equally.

From the various data of tests the ultimate adhesive strength for ordinary round or square rods may be taken at from 250 to 400 pounds per square inch, and the working strength at from 50 to 75 pounds per square inch. A round bar needs to be imbedded a length of about 60 diameters to develop its full strength. In case the bars are of large diameter and in any case in which such a length is difficult to secure, deformed or anchored bars are of especial value.

For deformed bars the safe working strength may be taken at about 100 pounds per square inch, the required length of the imbedding being about 37 diameters.

* Proc. Amer. Soc. of Testing Materials, 1904.

551. REINFORCED CONCRETE COLUMN DESIGN.—Reinforced concrete columns are of two general types: (1) Reinforcement all vertical and near the outer surface and tied at intervals principally to keep it in place; (2) reinforcement composed of circular or spiral wrappings or hoops of wire or steel bands or rods, with simply enough vertical rods to tie the wrappings to. The ultimate strength is raised by either of these types of reinforcement, but conclusive results have not been reached as to the true relative effect of different types and amounts of reinforcement.

There are two other types, which are concrete-protected columns rather than reinforced concrete columns: (3) Reinforcement composed of sufficient steel to carry the load, with sufficient concrete to protect it and increase the stiffness and factor of safety; (4) reinforcement composed of sufficient steel to act as a column strong enough to support all the dead loads, with sufficient concrete to support all the live loads.

The cost of columns of reinforced concrete is generally less than that of columns of steel or iron.

They occupy more space than columns of other materials usually employed. The following are the cross-section sizes of six columns of different materials, supporting a safe load of 50 tons, the length being 18 feet.*

Steel (two 6-inch latticed channels)	6 by 8 inches.
Cast-iron (hollow and round)	8 inches in diameter.
Yellow pine	11 by 11 inches.
Oak	12 by 12 inches.
White pine or spruce	13 by 13 inches.
Reinforced concrete	18 by 18 inches.

Regarding the length of reinforced concrete columns, building ordinances generally require that the ratio of length to least lateral dimension shall not be greater than from 12 to 16, usually 12. Flexure might be caused by a heavy load, and if the column were long enough the reinforcing rods might bend sufficiently to cause the concrete to fail.

The following are the limiting ratios of length to least lateral dimension given by the building laws of some of the largest cities:

* See "Reinforced Concrete," by Ernest McCullough.

New York (Manhattan)	12
New York (Brooklyn)	13
Chicago	12
Philadelphia	15
St. Louis	12
Buffalo	16
San Francisco	15
National Board of Fire Underwriters	12

It is rarely necessary to calculate these columns as *long* columns, as in ordinary construction the ratio of length to least width will seldom exceed from 12 to 15. Results of tests also show little or no difference in strength for ratios up to 20 or 25.

552. STRENGTH OF LONGITUDINALLY REINFORCED CONCRETE COLUMNS.—Some authorities determine the strength of concrete columns with longitudinal reinforcements by assuming that the reinforcement carries a load per square inch equal to the product of the working load per square inch in the concrete by the ratio of the moduluses of elasticity of the two materials. Thus, for example, if a load of 350 pounds per square inch is used for the concrete, and if 15 is taken as the ratio of the moduluses of elasticity of the steel and the concrete, $350 \times 15 = 5{,}250$ pounds per square inch is the allowable unit load on the steel.

Again, some authorities figure a higher unit stress on the concrete, allowing no load on the steel, assuming that its function is merely to resist flexure and therefore providing a percentage of steel area sufficient for that purpose only.

The relative intensities of compressive stress in the two materials will be as their moduluses of elasticity, as long as the steel and concrete adhere.

The following* are simple and reliable formulas for determining the safe strength of the column, the stress in the steel and the percentage of steel required for concrete columns with longitudinal reinforcement:

* This is the treatment of the subject given by Professors Turneaure and Maurer in "Principles of Reinforced Concrete Construction," to which the reader is referred for further detailed discussions of the theoretical strength of concrete columns and also discussions of numerous recent tests.

Let A = the total cross-section of the column;
" A_c = the cross-section of the concrete;
" A_s = the cross-section of the steel;
" p = the ratio of steel area to total area = A_s/A;
" f_c = the unit compressive stress in the concrete;
" f_s = the unit compressive stress in the steel;
" $n = E_s/E_c$ = the ratio of moduluses of steel and concrete at the given stress f_c;
Let E_c = the modulus of elasticity of the concrete;
" E_s = the modulus of elasticity of the steel;
" P = the total strength of a plain, non-reinforced concrete column for the stress of f_c;
" P' = the total strength of a reinforced concrete column for the stress f_c.

Then $P = f_c A$ (24)

and $P' = f_c A_c + f_s A_s = f_c (A - pA) + f_c n p A$

whence $P' = f_c A [1 + (n - 1) p]$, (25)

and dividing equation (25) by equation (24),

$$\frac{P'}{P} = 1 + (n - 1) p. \tag{26}$$

The relative increase in strength due to the reinforcement is given by

$$\frac{P' - P}{P} = (n - 1) p \tag{27}$$

The ultimate strength of the column may be affected by a low elastic limit in the steel, and in this case

$$P' = f_c A_c + f_s A_s \tag{28}$$

in which equation f_s is taken as the elastic limit strength of the steel.

If it is required to determine the relative strength of a reinforced concrete column and one which is without reinforcement, for a given percentage of steel, equation (26) may be used. For example, if $p = 1.5$ per cent and $n = 12$, then $\frac{P'}{P} = 1 + 0.165 = 1.165$. In this particular case the strength is increased 16½ per cent by a reinforcement of 1½ per cent, and, in general, for any given amount of reinforcement the relative increase in strength varies directly as n. The above relations show also that the economy of steel reinforcement depends upon the allowable working stresses in the concrete, as $f_s = nf_c$.

The following table* is useful in connection with the subject of the longitudinal reinforcement of concrete columns:

* From "Principles of Reinforced Concrete Construction," Turneaure and Maurer.

TABLE XLIII.

Longitudinal Reinforcement of Columns.

f_c, Pounds Per Square Inch	E_c, Pounds Per Square Inch	Ratio of Moduluses, n	f_s, Pounds Per Square Inch	Percentage Increase in Strength for Each 1 Per Cent Reinforcement
300	750000	40	12000	39
	1000000	30	9000	29
	1500000	20	6000	19
	2000000	15	4500	14
400	1000000	30	12000	29
	1500000	20	18000	19
	2000000	15	6000	14
	2500000	12	4800	11
500	1000000	30	15000	29
	1500000	20	10000	19
	2000000	15	7500	14
	2500000	12	6000	11
600	1500000	20	15000	19
	2000000	15	10000	14
	2500000	12	7200	11
	3000000	10	6000	9
800	2000000	15	12000	14
	2500000	12	9600	11
	3000000	10	8000	9
	3500000	8.6	6900	7.6

In this table the first column gives the various values of the working compressive stress in pounds per square inch in the concrete; the second column gives the various values of the moduluses of elasticity in pounds per inch for the concrete; the third column gives the various ratios of the moduluses of elasticity of steel and concrete; the fourth column gives the various values of the working stresses in pounds per square inch in the steel; and the fifth column gives the percentage increase in strength for each one per cent of steel.

This table indicates also that the working stresses in the reinforcement are relatively low except in the case of an unusual combination of high working compressive stresses in the concrete with a low modulus of elasticity in the same material. This combination is uncommon, because high-grade concrete mixtures, allowing high working compressive stresses, have a high modulus of elasticity.

553. EXAMPLES IN REINFORCED CONCRETE COLUMN DESIGN.—The following two examples will illustrate the general method of designing concrete columns with longitudinal reinforcement:

(1) *Example.* What is the safe strength of a column 14 inches

by 14 inches in cross-section and reinforced with 1 per cent of steel, the working stress of the concrete being taken at 350 pounds per square inch and n being taken at 12?

Solution. Using equation (25) and substituting, there results

$$P' = 350 \times 14 \times 14 \times \left(1 + 11 \times \frac{1}{100}\right) = 68,600\ (1 + 0.11) = 76,146 \text{ pounds.}$$

The strength of the concrete column without reinforcement is 68,600 pounds, and the relative increase in strength is 11 per cent. The unit compressive stress in the steel is $f_s = nf_c = 12 \times 350 = 4,200$ pounds per square inch.

(2) *Example.* The area of the cross-section of a column is 144 square inches, the load carried 70,000 pounds, the working unit stress for the concrete 400 pounds per square inch and n is 15. What is the required percentage of steel reinforcement?

Solution. The safe strength of the concrete column without reinforcement is $400 \times 144 = 57,600$ pounds. Using equation (26) and substituting, there results

$$\frac{P'}{P} = \frac{70,000}{57\ 600} = 1 + (15 - 1)\ p. \quad \text{Hence}$$

$$p = \frac{7}{5.76} - 1 \div 14 = 1.54 \text{ per cent.}$$

554. AMOUNT AND DISPOSITION OF LONGITUDINAL REINFORCEMENT.—The percentage of cross-section of longitudinal reinforcement usually varies from 1 per cent to 2½ per cent.

As in the case of beams, care should be taken in the disposition of the steel to avoid using too much of it and to avoid putting the rods too close together. The longitudinal reinforcing rods should not be placed nearer than 2 inches to the outside surfaces of the column because of the necessary concrete fire-protection; on the other hand, for purposes of resistance to lateral flexure, the rods should be placed as close to the outside surfaces as possible.

In order to resist the tendency to buckle and the resulting tendency of the concrete to crack and to split off, horizontal ties are used to hold the longitudinal reinforcing rods in position; but these ties should be so placed that the interior spaces are as full as possible, so as not to interfere with the proper placing of the concrete, which is usually poured into the column molds at their tops. The distance apart of these horizontal ties should be not greater than the diameter or the least lateral dimension of the column.

555. STRENGTH OF CONCRETE COLUMNS WITH WRAPPED OR HOOPED REINFORCEMENTS.—In a wrapped or hooped concrete column the resistance to rupture by compression is increased by the lateral restraint of the reinforcement, so that a higher unit compressive strength is developed. The concrete is prevented from spreading laterally.

The increase in strength due to lateral banding depends upon the rigidity of the bands, which in turn depends upon the amount of steel, the closeness of its spacing and its elastic limit.

Several investigators have deduced theoretical relations between the lateral and longitudinal stresses, and developed formulas for use in the design of these columns; and results of tests appear to accord in a general way with these theoretical relations.

A comparison of theoretical formulas and results of tests lead to the following conclusions:* "It would appear that *within the limit of elasticity* the hooped reinforcement is much less effective than longitudinal reinforcement; in fact it would seem that very little stress can be developed in the steel under elastic conditions as here assumed. Such reinforcement may, however, be quite effective in increasing the *ultimate* strength of a column. Hooped columns have a relatively large deformation, reaching at an early stage a deformation equal to the maximum for plain concrete. Under further loading the concrete is prevented by the banding from actual failure, but continues to compress and to expand laterally, increasing the tension in the bands, the elasticity of the bands rendering the column in large degree still elastic. Final failure occurs upon the breakage of the bands or with their excessive stretching. Banded columns thus exhibit a toughness or ductility much greater than other forms, but without a corresponding increase in stiffness under lower loads. Ultimate failure is likely to be long postponed after the first signs of rupture, and the column will sustain greatly increased loads even after the entire failure of the shell of concrete outside the bands."

Considère and others have made extensive theoretical and experimental investigations of hooped columns. Considère concludes that the ultimate strength is given by the formula

$$P' = f_c A + 2.4 f_s A_s,$$

or, since $p = A_s/A$

$$P' = f_c A + 2.4 f_s p A \qquad (29)$$

* "Principles of Reinforced Concrete Construction," Chapter III. Turneaure and Maurer.

Comparing this equation with equation (28), Article 552, it is seen that the reinforcing value of the steel is 2.4 times as much as in longitudinal reinforcement.

Some cities require certain formulas to be used, and in these cases the various building laws must be consulted. The following formula is the one used in New York City (Manhattan) for hooped columns:

$$P' \text{ (in tons)} = 0.8\, r^2 + 80 \frac{A_h}{k} r + 3A_s \qquad (30)$$

in which

P'=the total strength, in tons, of the column;

r=the radius, in inches, of the hoops or wrapping surrounding the concrete core;

A_h=the area, in square inches, of the cross-section of one hoop;

k=the pitch of the hoops;

A_s=the total cross-sectional area, in square inches of the *longitudinal* steel.

This formula is derived from a general formula developed by Mr. F. H. Dewey, of the Bureau of Buildings, Borough of Manhattan, N. Y., and takes this form, approximately, when f_c=350, p = 12 and when the safe unit tensile stress in the steel hoops is taken at 16,000 pounds per square inch.*

In comparing the results of tests made on full-sized columns with the results obtained by using this formula, there is found to be a close correspondence.

556. DISPOSITION AND DETAILS OF WRAPPED OR HOOPED COLUMN REINFORCEMENTS.—Steel bands or steel wire are used for this form of lateral reinforcement. With metal bands the joints are rivetted, and these joints should be made as strong as the unrivetted metal itself. In the case of wire it is wound spirally and continuously through the entire column length, with the ends bent down far enough to be firmly anchored in the concrete when poured and to resist the tension resulting from the lateral stresses developed in the concrete.

Two methods are employed for the details of wrapping and hooping at the top and bottom of columns at the floors. One omits the wrapping at the concrete floor construction sections in order to preserve the floor and column concrete bond. The method pre-

* For further notes on the derivation and limiting conditions of the above formula, see Chapter XXIV, in the "Architect's and Builder's Pocket-Book," Frank E. Kidder.

vails in cases in which there is a good solid floor construction around the column ends. The other method involves making the wrapping continuous through the floor construction.

3. MATERIALS OF REINFORCED CONCRETE CONSTRUCTION.

557. GENERAL CONSIDERATIONS.—Concretes in general have already been considered in the first general subdivision of this chapter and elements in Chapter IV. It remains to consider, (1) those special details and requirements of concretes pertaining to their use in reinforced concrete construction and (2) the properties of the reinforcing materials.

558. CONCRETES IN REINFORCED CONSTRUCTION.—While in mass concrete construction the stability of the structure depends in large part upon the *mass* and *weight* of the concrete, in reinforced concrete construction the *strength* of the materials is of greater importance. A relatively high grade of concrete should therefore generally be used. The sections of the constructive members being relatively small, and the stability of a structure being particularly dependent upon the integrity of every one of its parts, the concrete should be free from voids and of uniform quality throughout. In order also to adhere sufficiently to the reinforcement and to furnish adequate protection to it against damage by fire or by corrosion, it should be thoroughly sound. The greatest care should be exercised in its preparation and depositing in place, and regular and systematic tests should be made of it as actually used in each building during the progress of the work.

559. CEMENT FOR REINFORCED CONCRETE CONSTRUCTION.—Portland cement only should be used, and it should always be tested and made to meet the requirements of the standard specifications. (See Articles 179 and 180.) In this form of construction soundness, or constancy of volume, is particularly important, as unsound cement in some important supporting member, such as a column, may endanger an entire building; and the time of setting, or rapidity of hardening also, is particularly important, as either the building may have to receive a heavy load at an early date or the placing of such load may be long deferred.

560. THE AGGREGATE IN REINFORCED CONCRETE CONSTRUCTION.—Aggregates have already been considered under fire-proof materials and under concretes in general. (See

Articles 412, 498 and 515.) The requirements are generally the same for mass concrete and reinforced concrete construction, with the exception of those dealing with the size of the aggregates. While in large masses of concrete the size of the aggregates in largest diametrical dimension may run as high as 2½ inches, as in thick walls, large piers, foundations, etc., the common maximum sizes in reinforced work are from ¾ of an inch to 1¼ inches.

The building laws of many cities determine the maximum sizes of the aggregate to be used.

Philadelphia requires that "when stone is used with sand or gravel it must be of a size to pass through a one-inch ring, and 25 per cent of the whole must not be more than one-half the maximum size."

New York, Chicago, St. Louis and Buffalo require that the stones shall pass through a ¾-inch ring.

Cleveland allows a ¾-inch stone as a maximum for floors and fire-proofing and a 2-inch stone for other kinds of concrete construction.

San Francisco allows a 1-inch stone as a maximum for floors and fire-proofing and a 2-inch stone for foundation work.

561. THE PROPORTIONS OF THE MATERIALS FOR REINFORCED CONCRETE CONSTRUCTION.—The proportions depend upon the character and size of the materials themselves. Those commonly used vary from about 1:2:4 to 1:3:6 of cement, sand and broken stone or gravel, respectively. In many cities the building laws determine the proportions to be used. The 1:2:4 mixture is used more than any other, and richer mixtures than this are not common. It is also the one that has been up to this time the most frequently used in tests in reinforced concrete structural members.

These customary proportions should not be mistakingly adopted, however, in all cases as a matter of course; and for large and important operations a careful study of the materials and of the best proportions to use for economy and strength should be made. For any given materials the most economical mixture is in general the strongest.

New York requires that "the concrete be mixed in proportions of one of cement, two of sand and four of stone or gravel; or the proportions may be such that the resistance of the concrete to

crushing shall not be less than 2,000 pounds per square inch after hardening for twenty-eight days. The tests to determine this value must be made under the direction of the Superintendent of Buildings."

The requirements of St. Louis are the same as those for New York.

Philadelphia requires a 1:2:4 mixture.

Chicago requires a 1:3:5 mixture.

Boston and San Francisco require a mixture of one of cement to six of aggregate.

Cleveland requires no special mixture, but demands a resistance to crushing the same as that required by New York and St. Louis.

Buffalo requires a 1:2:5 mixture.

Although in the requirements of the above-mentioned cities the proportions are not the same in all, they all demand, however, a crushing strength of 2,000 pounds per square inch developed after twenty-eight days, and no mixtures that will not show this should ever be used.

562. THE CONSISTENCY OF CONCRETE IN REINFORCED CONSTRUCTION.—Concrete mixtures range from very dry to very wet, according to the amount of water used; and the purpose for which the concrete is employed regulates the consistency. The latest practice tends toward what is known as a "wet" mixture for use in reinforced work, a mixture of about the consistency of molasses and one which can be readily worked into place in the forms and around the reinforcements. Although thoroughly tamped and relatively dry concrete shows a slightly greater strength than a wet mixture, better results are usually obtained with the latter because of the difficulty and expense of securing a necessary amount of dry mixture tamping; and this is especially the case where a dense, homogeneous concrete is required. Reliability is more important than *maximum* strength in reinforced concrete construction. A dry mixture is relatively stronger, but demands more careful inspection when being put in place; a wet mixture is relatively weaker and demands a prompt pouring into the molds to counteract the tendency of the materials to segregate; but, on the whole, it gives better results.

563. STRENGTH AND ELASTIC PROPERTIES OF CONCRETE IN REINFORCED CONSTRUCTION.—These

have already been considered under concretes in general, mass concrete construction and under the general theory and design of reinforced concrete construction. (See especially Articles 503, 504, 515, 529 and 530.)

564. REINFORCING MATERIALS IN CONCRETE CONSTRUCTION.—Steel is now universally used as the reinforcing material for concrete construction. It is placed in various forms near the tension sides of structural members to resist the tensional stresses. It may assist also in resisting the shear, the diagonal tension and occasionally the compression stresses, as in doubly reinforced beams; and it gives additional compressive strength when used in columns.

565. GENERAL QUALITIES AND PROPERTIES OF THE STEEL.—The following is a convenient classification of the various *grades* of steel as a building material:

	Soft.	Medium.	Hard.
Elastic limit, lbs. per sq. in.......	30—35,000	35—40,000	50—60,000
Ultimate strength, lbs. per sq. in..	50—60,000	60—70,000	80—100,000

For all structural shapes the medium or mild steel is used, and for reinforced concrete work various grades have been used ranging from soft to quite hard. Authorities still differ regarding the question of the grade best suited to reinforced work.

"There exists considerable difference of opinion as to the *quality* of steel to be desired, especially with reference to the use of soft or hard material, or steel with low or high elastic limits. Certainly a material as hard as that formerly demonstrated 'hard bridge steel' is entirely suitable for reinforced construction. Such material has an elastic limit of about 40,000 pounds per square inch. Much material has been used of an elastic limit of 45,000 to 50,000 pounds per square inch and even higher, but a value beyond this is not to be desired. An elastic limit of 45,000 pounds per square inch is three times the working stress of 15,000 pounds per square inch. The use of steel with an elastic limit higher than this is unnecessary, and is of doubtful wisdom, as the ductility of a higher steel of the usual quality is not high. The authors would suggest a material of the quality employed for buildings with an *elastic limit* of from 35,000 to 40,000 pounds per square inch and *working stresses* of from 12,000 to 14,000 pounds per square inch."*

* 'Principles of Reinforced Concrete Construction." Turneaure and Muarer.

"*High carbon steel* has a greater percentage of carbon and is therefore more brittle. The use of high carbon steel would permit greater stresses in the reinforcement and consequently a less amount of steel and a greater economy in construction. On account of its greater brittleness, however, it is liable to sudden failures under stress. It is also often found to be cracked or broken when sent to the work, and unless very carefully inspected there is great liability of defective material getting into the structure. Furthermore, much of the so-called high carbon steel in practice has been found upon test to fall far short of the specifications. Its use is therefore to be avoided, unless special care is taken to secure an absolutely reliable article and to have it inspected and tested. For large important work this would be desirable. Ordinarily, however, mild steel should be used, as commercially it is manufactured and sold under such standard conditions that it is reliable. As the *modulus of elasticity* of high carbon steel is practically the same as that of medium steel, the deformation under any given loading is the same and there is no special advantage in the use of one over the other.

"The generally accepted *working stresses* for medium steel are 16,000 pounds per square inch in tension and 10,000 pounds per square inch in shear. Tests have shown that in cases where the failure of reinforced concrete beams is due to the failure of the reinforcement, the stress in the metal had not more than reached the yield point. This point is somewhat lower than the elastic limit. The working stress in the steel, therefore, should be a fixed proportion of the yield point or the elastic limit. It is held by some that this ratio should not be as high as one to two, but more nearly one to three, reducing the *working stress* in mild steel as given above to from 10,000 to 12,000 pounds per square inch. In using high carbon steel they would advocate a similar ratio of the elastic limit, whatever that may be, according to test. Ordinarily 20,000 pounds per square inch is taken as the *working stress* for high carbon steel."*

For the working unit *tensile* and *shearing stresses* allowed by the building laws of the larger cities of the United States, for steel in reinforced concrete construction, see Table XLI, Article 542.

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* Rudolph P. Miller in Chapter XXIV of the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

Modulus of Elasticity of Steel.—This is approximately the same for all grades of steel and is generally taken at 30,000,000 pounds per square inch.

Elastic Elongation of Steel.—The elongation of the steel at its elastic limit is considered in determining the deformations, and for the three grades of steel and the modulus of elasticity given above the elongations per unit of length at the elastic limit are as follows:

For soft steel..............................	0.0010 — 0.0012
For medium steel...........................	0.0012 — 0.0013
For hard steel..............................	0.0017 — 0.0020

Coefficient of Expansion.—The coefficient of expansion of steel may be taken at 0.0000065 per 1° Fahr.

566. PROPERTIES OF CONCRETE AND STEEL IN COMBINATION.—These include the *adhesion* of the concrete and the reinforcements, the *mechanical bond,* the *ratio of the moduluses of elasticity,* the *tensile strength* and *elongation* of concrete when reinforced and the relative *contraction* and *expansion* due to temperature or shrinkage.

The most important of these have already been discussed under general theory and design and elsewhere, and for any further consideration of the subjects the reader is referred to the various treatises on the theory of reinforced concrete construction.

4. TYPES OF REINFORCEMENTS.

567. GENERAL CONSIDERATIONS.—The rapid development of reinforced concrete construction has resulted in the introduction of numerous shapes and combinations of bars and rods, many of them patented and some of them used as the elements of more or less complete systems of reinforcement.

The form and size of reinforcing steel must be such as will allow it to be readily incorporated into the concrete and to form a monolithic structure. Comparatively small cross-sections of steel members are required, leading to the use of rods or bars varying in *cross-sectional size* from ¼ to ⅜ of an inch for light work up to 1½ to 2 inches for heavy girders and columns. Cross-sectional sizes usually refer to the cross-sections of square bars of corresponding sizes.

568. GENERAL CLASSES OF REINFORCEMENTS.—Reinforcements may be classified generally as follows:

1. Unframed bars or rods;
   (1) Plain,
   (2) Deformed,
   (3) With stirrup or truss attachments.
2. Framed or tied bars or rods forming so-called "Unit Systems";
   (1) Plain bars or rods,
   (2) Deformed bars or rods.

569. PLAIN REINFORCING BARS AND RODS.—The shape of the cross-section of plain bars is round, square, rectangular, angle-shaped, T-shaped, cruciform, I-shaped, etc.

Plain round bars have been used in Europe and the United States for many years. Square bars are not so easily obtained nor as convenient in use as round bars, but they show about the same adhesive strength as round bars. Rectangular cross-sectioned or flat bars are not considered desirable, their adhesion to the concrete being considerably below that of round or square bars; and it is claimed by some that square and other sharp-edged bars cause a tendency to start initial cracks in the concrete during the setting shrinkage.

When plain bars are used either the adhesion alone of the steel and concrete is depended upon for the transmission of stress, or the ends of the bars are anchored into the concrete, thus developing nearly their full tensile strength.

570. DEFORMED REINFORCING BARS AND RODS.—Many special shapes of bars have been devised, the principal object of which is to supplement the adhesion by a bonding of the materials, usually called a "mechanical bond."

The immediately following articles briefly describe and illustrate some of the forms used. It is not possible to describe and illustrate all of them, and those mentioned do not by any means exhaust the list of excellent reinforcements on the market.

571. COLD-TWISTED LUG BAR.—Fig. 504 shows the cold-twisted lug bar, a bar with small lugs or projections placed at regular intervals. It is manufactured by the General Fire-proofing Company, Youngstown, Ohio, in various sizes of cross-sectional area corresponding to: ¼, ½, ⅝, ¾, ⅞, 1, 1⅛ and 1¼-inch square bars. The manufacturers of this bar claim that the elastic limit and ultimate strength are increased and the elongation

decreased by the twisting, and that the tendency to untwist under tensional stress is diminished by the lugs.

572. CUP BAR.—Fig. 505 shows the cup bar, made by the Trussed Concrete Steel Company, Detroit, Mich., and constructed with projecting longitudinal ribs and transverse divisions,

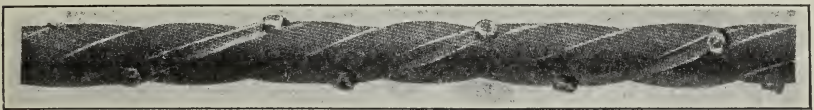


Fig. 504. Cold-twisted Lug Bar.

which form hollows or "cups" to be filled with the surrounding concrete, and thus to aid in resisting the tendency to slip or to pull out, and also the tendency to shear the concrete near and along the bar.

573. DE MAN BAR.—Fig. 506 shows the De Man bar, a flat bar, A, with twists, B, at short intervals of from 2 to 4 inches, according to the size of the bars, which varies from $\frac{1}{16}$ to $\frac{1}{4}$ of an inch in thickness and from $\frac{1}{4}$ of an inch to $1\frac{1}{2}$ inches in width. The purpose of the undulating twists is to strengthen the bond.

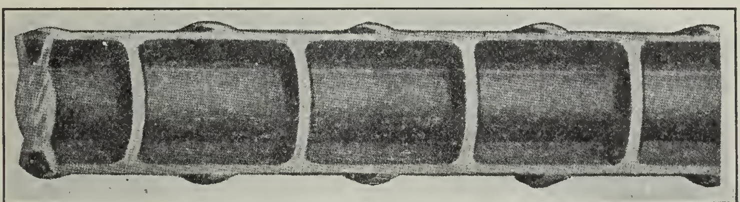


Fig. 505. Cup Bar.

574. DIAMOND BAR.—Fig. 507 shows the diamond bar, invented by Mr. William Mueser and manufactured by the Concrete Steel Engineering Company, New York, in sizes varying from $\frac{1}{4}$ of an inch up to $1\frac{1}{4}$ inches, the weights and areas being reckoned equal to those of plain square bars of like denominations. The principal advantages claimed for this bar are the uniform areas of the cross-sections and the saving of any waste of steel used to make deformations for the sole purpose of forming a bond. It is one of the most recent types of rolled bars.

575. JOHNSON CORRUGATED BAR.—Figs. 508, 509, 510 and 511 show the Johnson corrugated bar, a patented bar, invented by Mr. A. L. Johnson and made by the Expanded Metal and Corrugated Bar Company, St. Louis, Mo. The corrugations are arranged as shown, to effect the mechanical bond; and the alternating of their positions leaves the effective area the same throughout. These bars are rolled to various sizes and weights, and are of four types, as follows: "corrugated rounds" shown in Fig. 508; "corrugated squares, new style," shown in Fig. 509; "corrugated squares, old style," shown in Fig. 510; and "corrugated flats, universal type," shown in Fig. 511. (See also Article 599.)

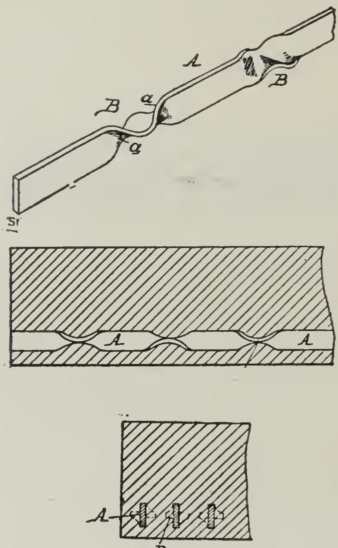


Fig. 506. De Man Undulated Bar.

576. PRIDDLE BAR.—Fig. 512 shows the Priddle "inner or internal bond bar" for concrete reinforcement, patented by Mr. Arthur Priddle, San Francisco, Cal. Flanged slits are made in the flat bar, and there is no loss in cross-sectional area. The manufacturers claim that the bar is a positive tie, does not depend upon the mechanical bond of the concrete and therefore requires a relatively small amount of metal.

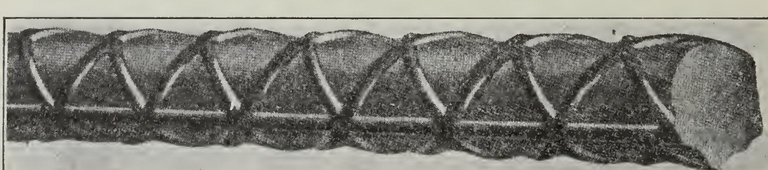


Fig. 507. Diamond Bar.

577. RANSOME BAR.—Fig. 513 shows the Ransome twisted bar. It is one of the oldest types of reinforcing steel and was invented by Mr. E. L. Ransome, of the Ransome & Smith Company, and used as long ago as 1894. The patents on these bars, which are manufactured from square bars twisted cold, have now expired,

and any one may make, sell or use them. The Ransome Concrete Machinery Company, New York, has all the special machinery and facilities for furnishing them, and they are made in many sizes,

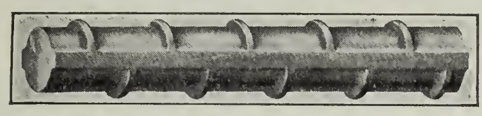


Fig. 508. Johnson Bar. Corrugated Rounds.

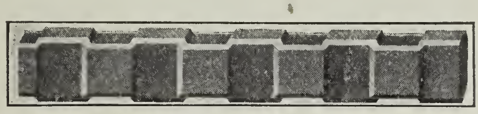


Fig. 509. Johnson Bar. Corrugated Squares. New Style.

Fig. 510. Johnson Bar. Corrugated Squares. Old Style.

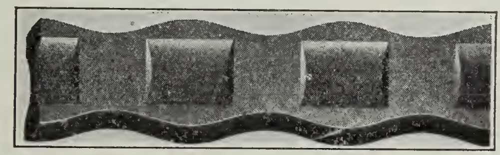


Fig. 511. Johnson Bar. Corrugated Flats, Universal Type.

from ¼ to 1¼-inch, and larger when required. A working tensile stress of about 20,000 pounds per square inch is generally assumed, as the tensile strength is increased by the twisting.

Fig. 512. Priddle Inner Bond Bar.

Although for convenience this bar is mentioned here with the deformed reinforcing bars and rods, it is not, strictly speaking, a "deformed" bar.

578. THACHER BAR.—Fig. 514 shows the Thacher bar, sometimes called the Thacher "bulb" bar, invented and patented by Mr. Edwin Thacher, of the Concrete Steel Engineering Company, New York; used extensively in buildings, but particularly in arches and bridges; and now largely superseded by the Diamond bar, made by the same manufacturers, and described in Article 574. It is rerolled from round bars to the shape indicated.

579. BARS WITH STIRRUP AND TRUSS ATTACHMENTS.—There are several types of reinforcements in which plain

Fig. 513. Ransome Twisted Bar.

bars are generally used, with various systems of stirrup connections, bendings and trussing of the bars, etc.; and with different methods of securing and anchoring the members in the concrete or at the supports. The Golding, Hennebique, Kahn, etc., systems are illustrations of this type.

580. GOLDING BAR.—Fig. 515 shows the "Golding monolith steel bar," manufactured by the Monolith Steel Company of Washington, D. C., and the invention of Mr. J. F. Golding. It is a "plain" bar and the side grooves serve to hold the stirrups as well as to increase the surface in contact with the concrete. The cross-

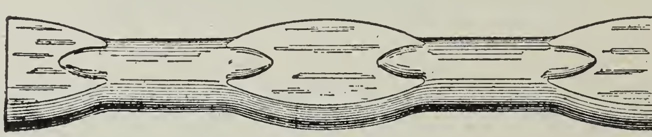


Fig. 514. Thacher Bulb Bar.

section is uniform in shape throughout, except at the joining of the stirrups, where the change in shape only is slight. The stirrups will tear apart before separating from the bar. They may be placed and spaced wherever desired. These bars may be had in sizes equivalent to 1½, 1, 8/10 and ½-inch square bars; giving areas equal, respectively, to 2¼, 1, 64/100 and ¼ square inches; and having web members of, respectively, ½, ⅜, ¼ and $\frac{3}{16}$-size.

581. HENNEBIQUE SYSTEM.—Fig. 516 shows the bars and stirrups and their general arrangement in the Hennebique sys-

tem of beam and girder reinforcement. Plain bars are used in the construction shown and their ends are split and flared out to form an anchorage in the concrete over the supports. Other methods of anchoring the tension bars are employed in various constructions, such as bending the ends of the bars, using nuts and washers, running the bars through steel column web-plates or through angle-brackets and securing them with nuts, etc. (See Articles 590 and 603.)

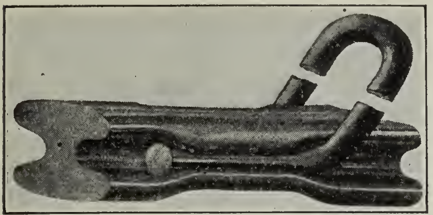


Fig. 515. Golding Monolith Steel Bar.

582. KAHN BAR.—Fig. 517 shows in perspective the general type of the Kahn trussed bar made by the Trussed Concrete Steel Company, Detroit, Mich., with cross-section of bar and with diagrams showing analogy to truss action and general method of using the bars in beam and floor construction. (See also Figs. 29 and 30.) The stirrups are parts of the reinforcing bar itself, which is a square bar placed with the diagonals vertical and horizontal and having webs rolled on the two side edges. The shearing of these webs along a part of their length and the bending up of the sheared portions form the stirrups, which may turn up in pairs as shown in the figure or in alternating single stirrups to make closer spacing.

The positive security of the stirrups and the location of the maximum cross-sections of metal at the points of greatest bending moment are two important advantages of this system. Two of the disadvantages which are mentioned are, for deep beams, the difficulty of making the stirrups long enough and, in all beams, the tendency of the webs to divide the concrete into two parts or layers.

Fig. 518 is a diagram section of the Kahn bar used for convenience in figuring sizes. The following are the sizes in which it is made:

Size.	A	B	C	Weight per foot.	Area sq. in.
1½"x½"	1½	½	⅛	1.4	0.38
$2\frac{3}{16}$"x¾"	$2\frac{3}{16}$	¾	$\frac{3}{16}$	2.7	0.78
3 "x1 "	3	1	¼	4.8	1.42
3¾"x1¼"	3¾	1¼	¼	6.9	2.00

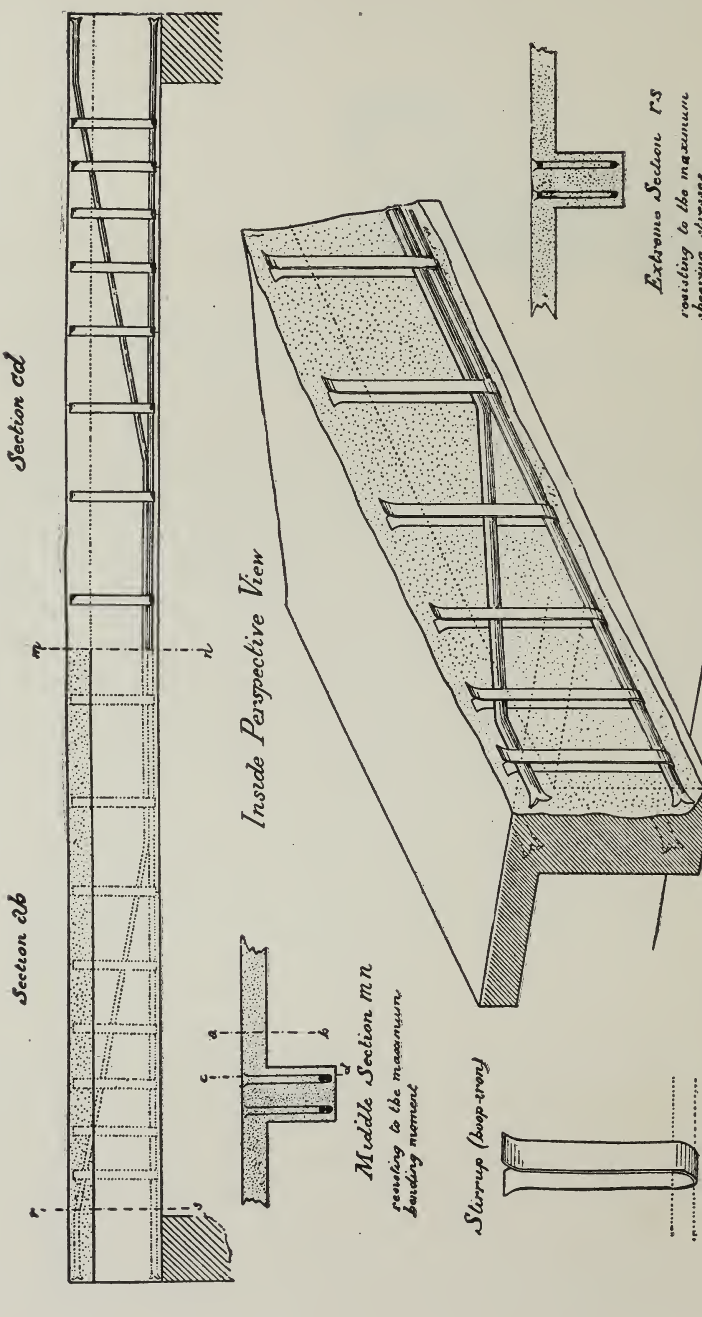


Fig. 516. Concrete Beam and Girder Reinforcement. Hennebique System.

583. STIRRUPS IN CONCRETE REINFORCEMENT.—These are used vertically or diagonally in order to overcome the tendency in loaded beams to develop diagonal cracks and breaks near the supports. These failures are probably due partly to the

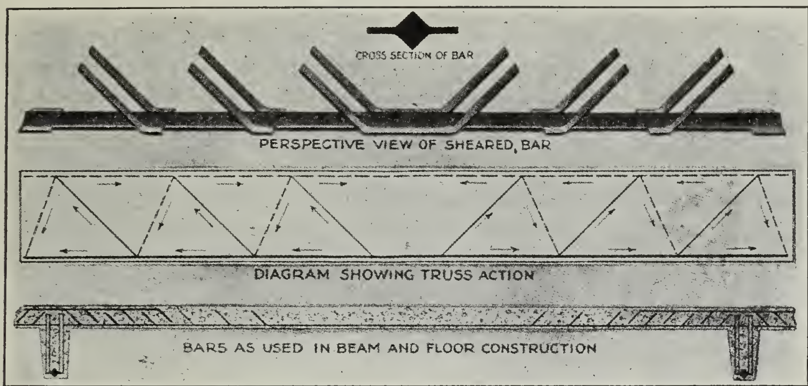


Fig. 517. Kahn Trussed Bar. Truss Action Diagram. Floor Construction.

horizontal and vertical shear, which is a maximum at the supports, and partly to internal tension caused by a stretching and slipping of the reinforcing rods. It is therefore important to attach the stirrups securely to the tension rods, firmly anchor them at the ends and secure the greatest possible adhesion of steel to concrete by mechanical bond or otherwise.

The shear or diagonal tension has already been discussed in Article 548, and the adhesion of the concrete to the reinforcement in Article 550.

584. UNIT SYSTEMS.—In the articles treating of the general theory and design of reinforced concrete construction the importance of keeping the reinforcement in an exact position was explained. It is for the purpose of maintaining this exact position of the reinforcement that the so-called "unit" systems are used. These unit systems consist generally of the horizontal and curved and bent tension rods, generally not deformed, and the stirrups, all framed and tied together into one unit, so that they can be readily set in their exact positions and kept there, with little

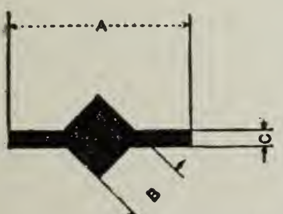


Fig. 518. Kahn Trussed Bar. Cross-section.

chance of their moving in the forms while the concrete is being filled in.

Some typical unit systems are described and illustrated in the following articles. There are other excellent systems in addition to those mentioned to illustrate the construction.

585. CUMMINGS LOOP TRUSS UNIT FRAME.—Fig. 519 shows the Cummings system of reinforcing concrete beams and girders, the frames being manufactured by the Electric Welding Company, Pittsburg, Pa. The drawing shows it in position, as used, as at A and B, and closed or "knocked down" flat for convenience and economy in shipping, as at C, D and E. Inverted U-shaped stirrups are attached to the longitudinal bars and secured to them by patent "chair-locks" or "saddles." (See also Article 598.)

586. ECONOMY UNIT FRAME.—Figs. 520 to 524 show this

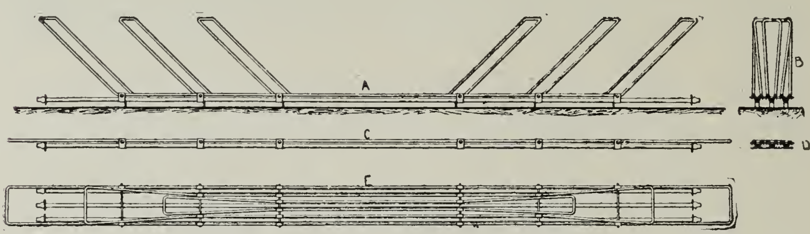


Fig. 519. Cummings Loop Truss Frame.

collapsible frame, with details also of floor slab reinforcing. It is manufactured by the Expanded Metal and Corrugated Bar Company, St. Louis, Mo. It is easily shipped and placed in the form as a unit, with the stirrups definitely spaced and provided with separators, which accurately fix and hold the main reinforcing bars in position.

Fig. 520 shows bars in place in stirrup frame ready for concreting.

Fig. 521 shows frame collapsed, ready for shipping.

Fig. 522 shows a cross-section through a concrete beam and the Economy unit frame; and also shows plan and elevation of saddle or separator, which is slotted to receive the bars.

Fig. 523 shows section and perspective of concrete floor slab with method of spacing the reinforcing rods with spring lock bar spacer, made of steel wire and sprung over the bars.

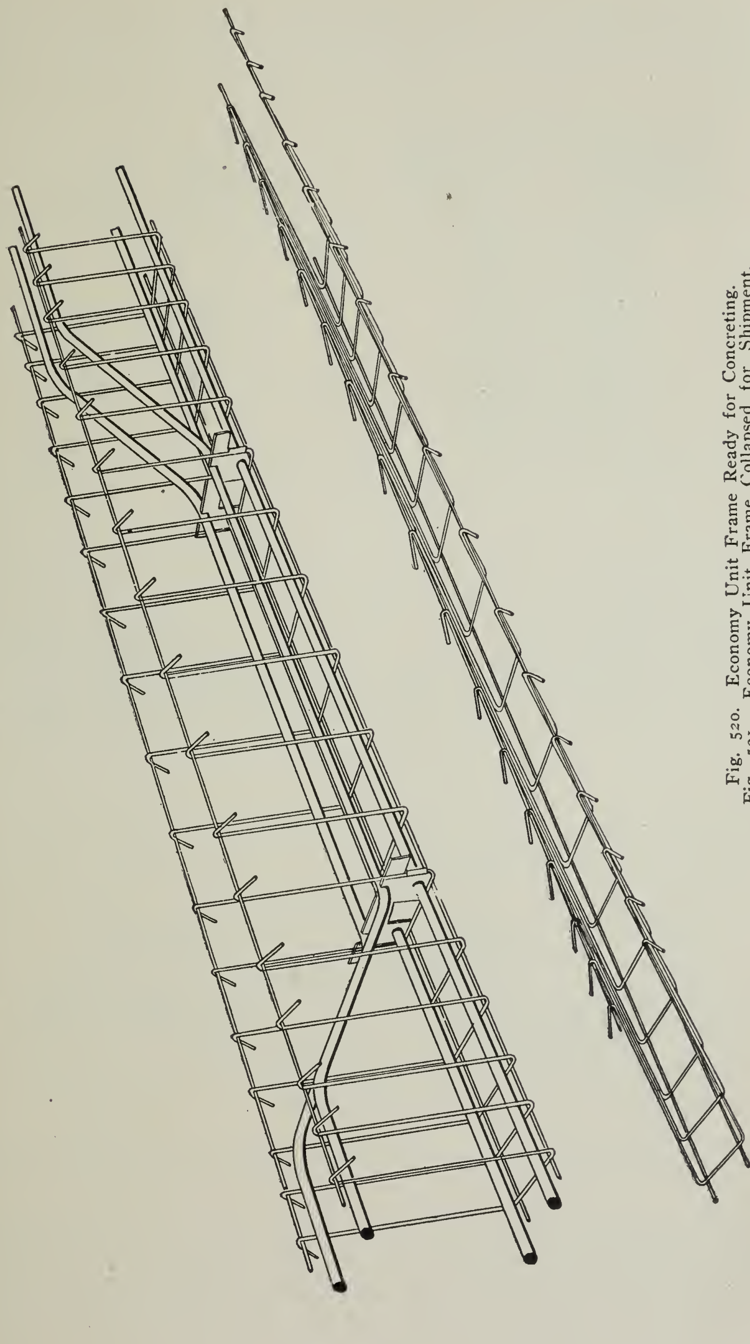
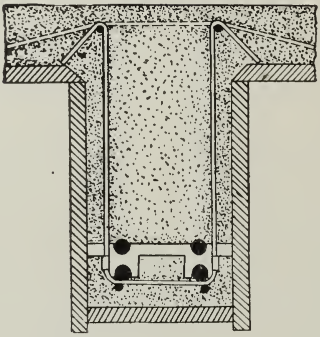
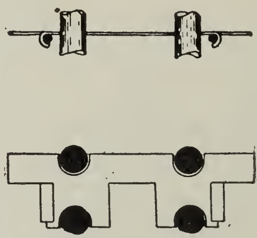


Fig. 520. Economy Unit Frame Ready for Concreting.
Fig. 521. Economy Unit Frame Collapsed for Shipment.

Fig. 524 shows cross-section through concrete floor slab, wood centering and slab rods and shows also the stool-lock spacers used



Section Through Beam.



Plain and Elevation of Saddle.

Fig. 522. Economy Unit Frame.

not only to separate and hold the slab rods, but also to keep the rods at a certain fixed distance above the wooden centers and the lower surface of the concrete slab.

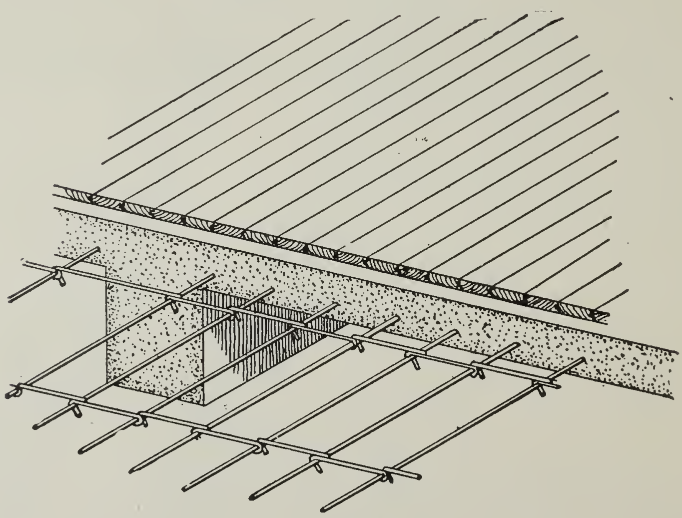


Fig. 523. Concrete Floor Slab with Reinforcing Rods and Spring-lock Bar Spacers.

The rods, spacers, etc., shown are made by the manufacturers of the Economy unit frame.

587. PIN-CONNECTED GIRDER FRAME.—Figs. 525 and

526 show the pin-connected girder frame manufactured by the General Fire-proofing Company, Youngstown, Ohio.

Fig. 525 shows the assembled work of the frame for the girder

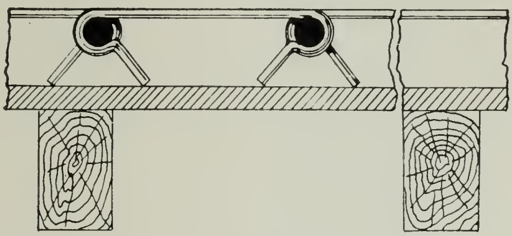


Fig. 524. Rods and Stool-lock Spacers for Concrete Floor Slabs.

and the connections at the columns, and Fig. 526 shows a section through reinforced concrete girder and columns with the frame and connections in place.

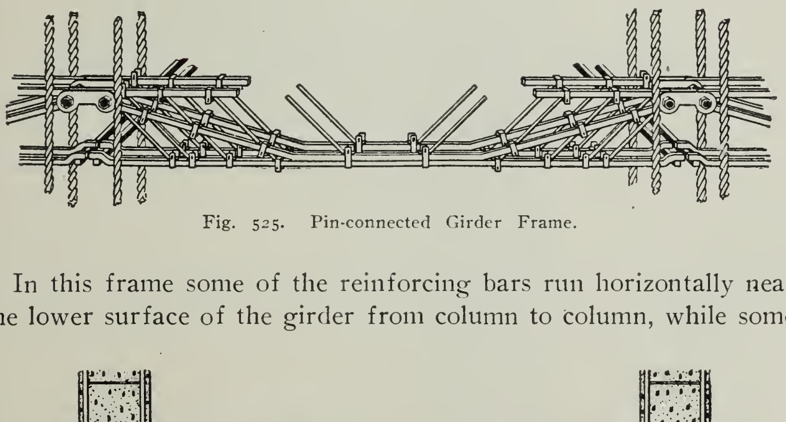


Fig. 525. Pin-connected Girder Frame.

In this frame some of the reinforcing bars run horizontally near the lower surface of the girder from column to column, while some

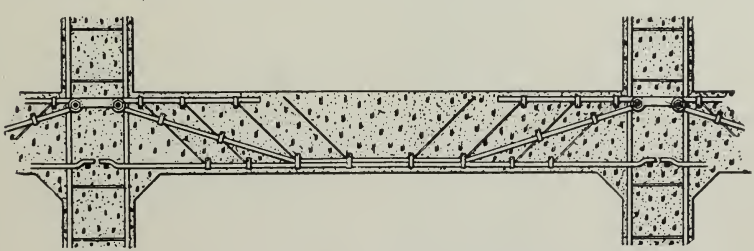


Fig. 526. Concrete Girder and Columns with Pin-connected Frame.

are bent up toward the supports, as shown, and are bolted together over them by means of links and pins, thus making a rigid continuous framework of steel from wall to wall. The disposition of

the stirrups is regulated by the varying requirements of different cases.

588. UNIT CONCRETE-STEEL FRAME.—Figs. 527, 528 and 530 show the unit girder frame in perspective and in sections, and Fig. 529 shows the unit socket used to support the frame. These unit frames and accessories are manufactured by the Unit Concrete Steel Frame Company, Philadelphia, Pa.

Fig. 527 shows the original general arrangement of the unit type of reinforced girder construction. Some of the longitudinal bars are bent up before they reach the supports. The stirrups are U-shaped and have holes punched through them near their upper ends to receive the rods for the floor slabs. These frames, which are designed, built, delivered, erected and supported as units, are specially designed for each span, each member being made the necessary size and shape, with tension and shear members properly spaced. The concrete can be readily tamped with little or no disturbance of the reinforcing members. The frames are easily adapted to any system of slab reinforcement, which is always laced through the stirrups, making a T-sectional construction.

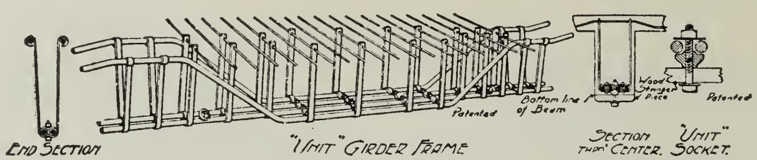


Fig. 527. Unit Girder Frame. General Construction.

Fig. 528 shows longitudinal section and cross-sections through a unit girder frame of ordinary and usual width.

Fig. 529 shows the patented unit socket used to support the frame. It is designed to locate the center of action of the steel reinforcement before the concrete is put into the molds; to allow inspection before concreting; to prevent any movement from the tamping; and to furnish supports for any required suspended ceilings, partitions, shafting, pipes, fixtures, etc., without the use of expansion-bolts.

Fig. 530 shows an isometric perspective view, looking up, of a portion of reinforced concrete floor slabs, beams, girders and columns, with the unit concrete-steel frame system of construction. The design shown is for heavy floor loads.

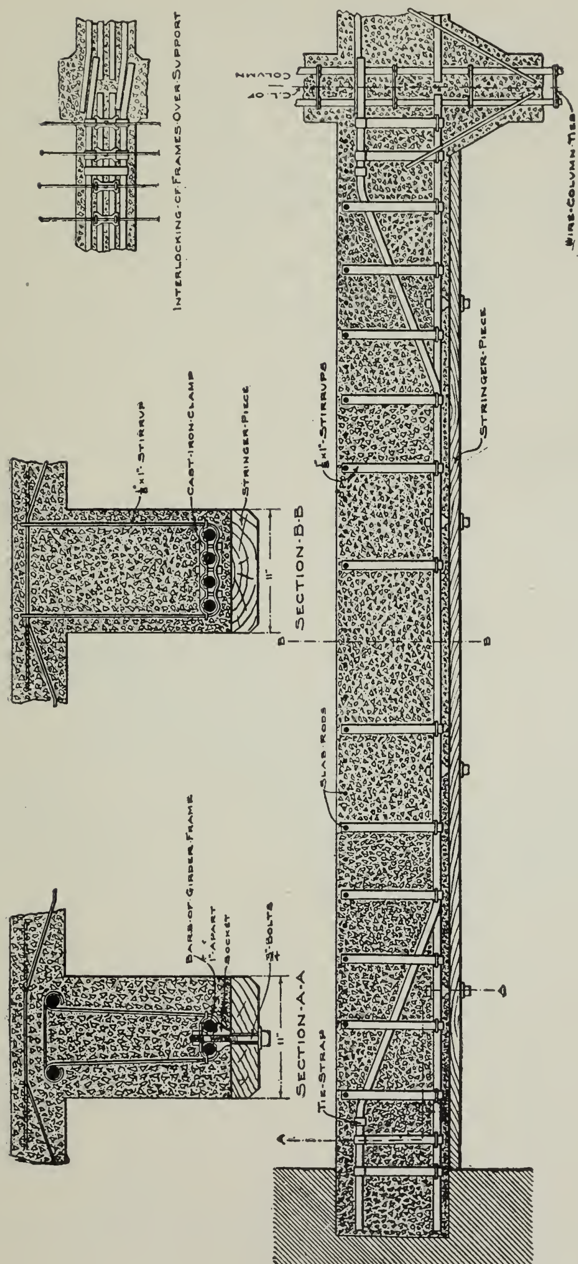


Fig. 528. Unit Girder Frame for Ordinary Widths.

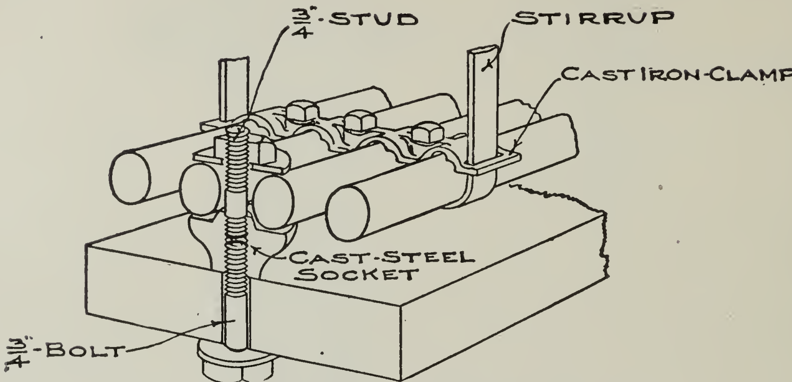


Fig. 529. Unit Socket for Supporting Girder Frame.

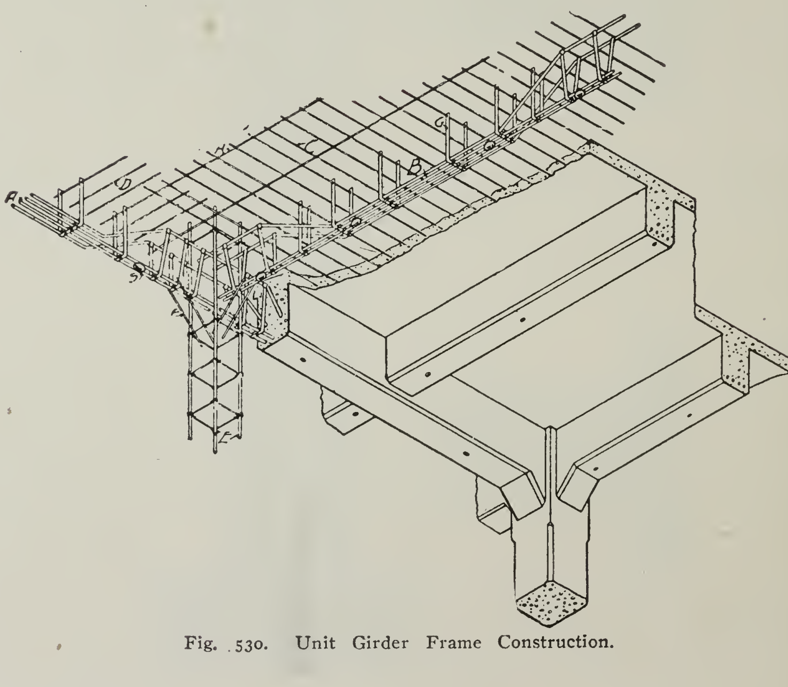


Fig. 530. Unit Girder Frame Construction.

589. CONCRETE COLUMN AND PIER REINFORCEMENT.—The following articles describe and illustrate some of the concrete column and pier reinforcements. By referring also to the articles dealing with the different types and kinds of reinforced concrete construction in the following fifth subdivision of this chapter, the reader will find additional illustrations of concrete column reinforcement in the figures showing the general beam, girder and floor construction.

590. ILLUSTRATIVE EXAMPLES OF CONCRETE COLUMN REINFORCEMENT.—Fig. 531 shows the Hennebique column reinforcement, with illustration of lower end of column and footing connection. The rods are imbedded in the

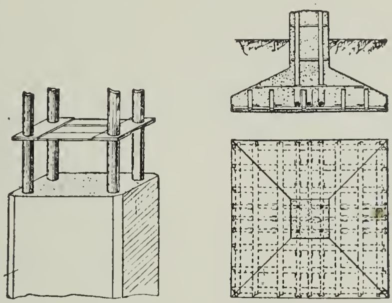


Fig. 531. Hennebique Column and Footing Reinforcement.

concrete near the periphery. They are connected by means of ties of hoop-iron or wire. Thus the radius of gyration is increased and the rods take care of the tensile stresses which occur from eccentric loading or from buckling of the columns. The horizontal ties prevent the buckling of the rods and increase the strength of the concrete. They form a hooped column, the properties of which have been investigated by M. Considère and others.

The footing of the column is also of a very simple construction. Steel rods, carefully placed, form with the concrete a flat plate which distributes the load equally over the soil. (See also Articles 581 and 603.)

Fig. 532* shows the column reinforcement, footing connections and footings for the interior columns of the Bullock Electric Com-

* Courtesy of the Atlas Portland Cement Company, New York.

pany's machine shop, at Norwood, Ohio, erected by the Ferro Concrete Construction Company, Cincinnati, Ohio.

Fig. 533 shows the Cummings hooped column. Hooped concrete columns were first used in the United States by Mr. Robert A. Cummings. (See also Article 598.)

The hooped columns of individual steel hoops are horizontally spaced upon vertical spacing members at regular distances, usually two or three inches. For small-size hooping the spacing verticals consist of flat steel strips with projections arranged to clinch both top and bottom of each band, thus constituting a secure and rigid

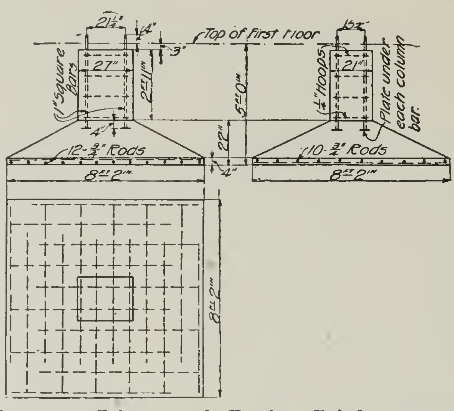


Fig. 532. Column and Footing Reinforcement, Bullock Electric Company's Buildings, Norwood, Ohio.

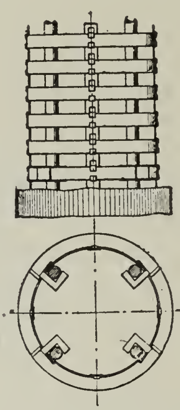


Fig. 533. Cummings Hooped Column.

fastening. For heavy hooping the spacing verticals may be of structural steel punched for staple fastenings.

Fig. 534 shows the column hooping and spacing bar made by the Trussed Concrete Steel Company, Detroit, Mich. The standard pitches are 1, 2, 3, 4, 5 and 6 inches and the hooping material either No. O wire or ½ by ¼-inch bands.

The spacing bar is provided with a projecting rib, which is sheared from the main section to form projecting fins. The spacing of these fins corresponds to the standard pitch of the hooping bands and when bent around the bands, spaces and holds the hooping in exact position.

Hooping material is rolled at the shops to various diameters; and

the proper number of coils in a continuous piece can be supplied when the pitch and story-heights are known.

In assembling the reinforcement for a hooped column four or more spacing bars are placed on a circular form, with the fin side outward. The hooping is then slipped on and each band is placed so that the fins can be bent around it and thus hold it rigidly in position. The longitudinal reinforcing bars are then placed inside the core and wired to the shell at three or more points. The entire reinforcement for the column is then placed as a unit in the work.

Fig. 535 shows the system of concrete column reinforcement

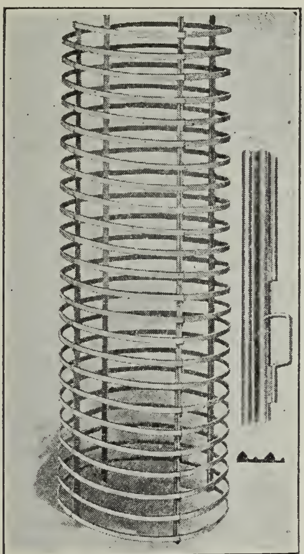


Fig. 534. Column Hooping and Spacing Bar.

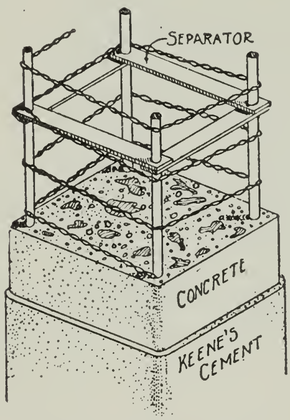


Fig. 535. Column Reinforcement Hinchman-Renton System.

introduced by the Hinchman-Renton Fire-proofing Company, Denver, Col.

Fig. 536 shows the system of concrete column reinforcement used by the American Steel and Wire Company, New York and Chicago. The first illustration shows the arrangement for a square column and the second the arrangement for a round column. The triangular mesh steel wire is used and is made with hinged joints on longitudinals, either 4 or 8 inches apart. The reinforcing material

can be readily formed into triangular, round or irregular-shaped cages without bending the wires.

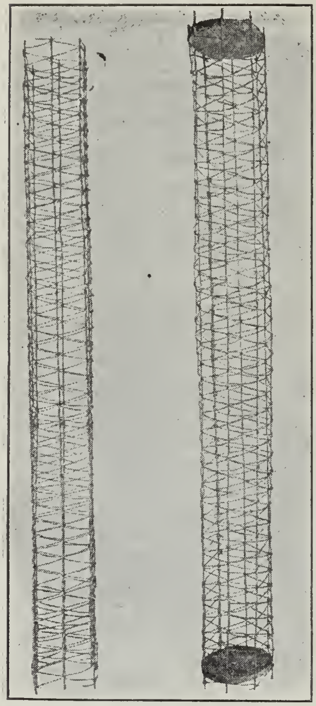


Fig. 536. Wire Reinforcement for Columns. American Steel and Wire Company.

Fig. 537 shows a detail of a wall column or pier of the Salem Laundry building, Salem, Mass., designed by Ballinger & Perrot, Philadelphia, Pa.

The exterior walls are a combination of concrete blocks and monolithic concrete, the wall columns being built up of blocks, while the base-course, the panels under the windows and the cornices, including the name and date inscriptions, were cast in position. The blocks are composed of what is known as "dry mixture" of 1 part of cement and 3 parts of sand, and were made near the building site, as needed, being allowed to season from ten days to two weeks before being placed in the walls. They were made hollow, with molded vertical grooves on the exposed surfaces, similar to "droved" stonework, rebates being made at the top of each block so that recessed joints occurred at each course as it was built into the wall. After being set in position those blocks bearing concentrated loads were reinforced with ¾-inch steel rods

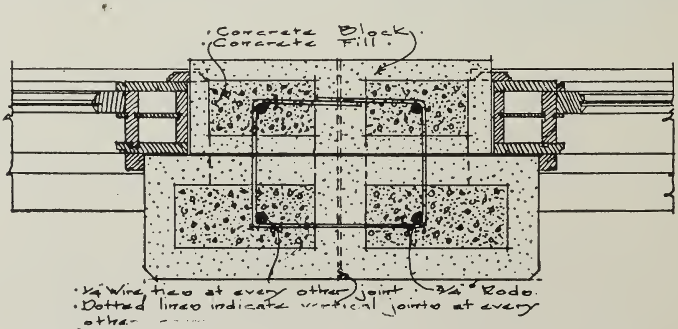


Fig. 537. Concrete Wall Column, Laundry Building, Salem, Mass.

placed vertically inside the hollow spaces in the blocks and tied together at every third course with ¼-inch steel wire ties in the

manner shown. The hollow spaces were then filled solid with a grout of 1 part of cement and 3 parts of sand.

Fig. 538 shows the Kahn trussed bar adapted to concrete column reinforcement as well as to girders, beams and floor slabs. It is manufactured by the Trussed Concrete Steel Company, Detroit, Mich. This bar has been described in Article 582 and illustrated in Figs. 29, 30, 517 and 518.

Fig. 539 shows the patented spiral wire reinforcement for concrete columns manufactured by the F. P. Smith Wire and Iron Works, Chicago, Ill. The wire is cold-drawn high or low car-

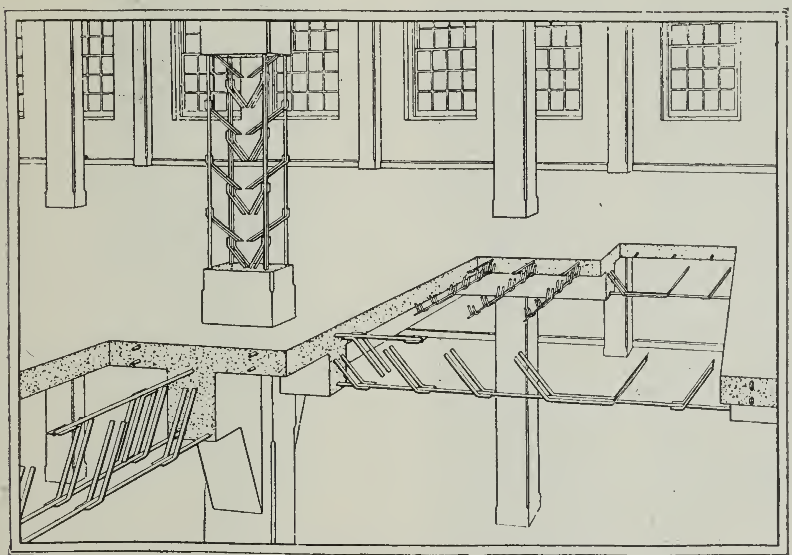


Fig. 538. Kahn Trussed Bar Reinforcement.

bon wire with a high elastic limit and tensile strength and is continuously wound around and securely clinched to the vertical reinforcing bars. These bars are shown in detail in Fig. 540, which is about one-third full size. These columns are usually furnished with approximately 2 per cent of vertical reinforcement.

Fig. 541 shows the unit column frame of the Unit Concrete Steel Company, Chicago, Ill.

Fig. 542 shows the spiral reinforcing for columns manufactured by the American System of Reinforcing for Concrete Construction, Chicago, Ill.

It consists of varying sizes of wire ranging from No. 7 gauge up to 3/8 of an inch, coiled in the form of a helix, spaced from 1 inch to 3 inches, and in lengths as required. The spacing device is a heavy wire, crimped to maintain the proper distance of spiral, with a flat piece of steel behind, securely bolted to the crimped wire.

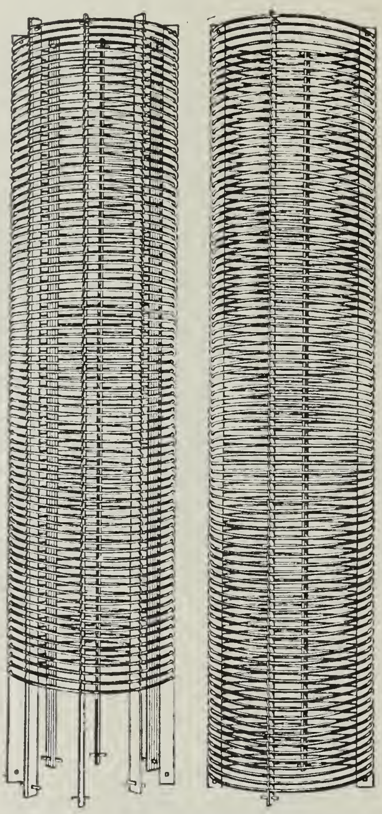


Fig. 539. Column Reinforcement. Patented Spiral Wire.

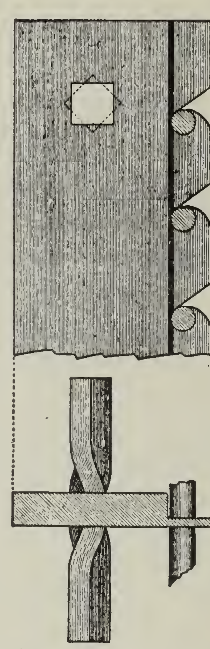


Fig. 540. Detail of Patented Spiral Wire for Column Reinforcement.

Fig. 543 shows the column reinforcement of the Monolith Steel Company, Washington, D. C.

In this system the Golding bars already described in Article 580 are used and around them is wound spirally flat band hooping. Staples are crimped into the groove on one side of each bar at proper intervals; the necessary number of reinforcing bars are assembled on a circular form, with the stapled sides outward; the

hooping is then wound around them, so that it passes between the outwardly projecting legs of each staple; these are then bent down so as to closely enclose the hooping and hold it rigidly in position. The reinforcement of the column is thus assembled as a unit; the form made for assembling is made to collapse, and the assembled reinforcement taken off and set up in position.

Fig. 544 shows what is known as the "T. I. M." Patent Rein-

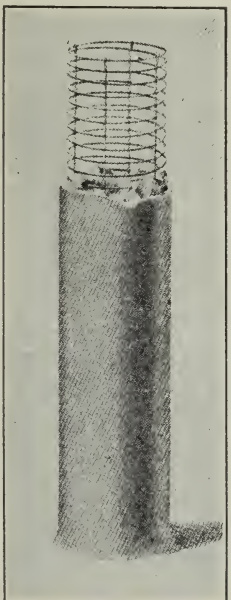


Fig. 541. Column Reinforcement. Unit Concrete Steel Company, Chicago, Ill.

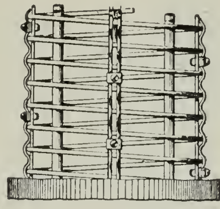


Fig. 542. Column Reinforcement Used by the American System of Reinforcing for Concrete Construction, Chicago, Ill.

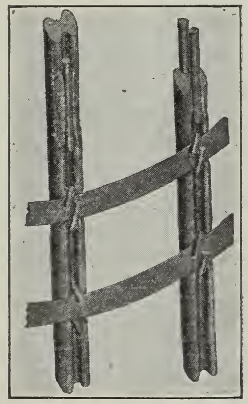


Fig. 543. The Golding Bar System of Concrete Column Reinforcement.

forced Column, manufactured by the New York Fire-proof Column Company, Hoboken, N. J. These columns are constructed of a rolled steel shell filled with concrete, in the middle of which is a steel pin.

5. TYPES AND SYSTEMS OF REINFORCED CONCRETE CONSTRUCTION.

591. GENERAL CONSIDERATIONS.—Having considered some of the commonly used *types of reinforcement* in the preceding

subdivision, some of the types and *systems of reinforced concrete construction* will be referred to, principally by means of typical illustrations in the figures. There are now so many systems and variations in details that it is impossible to even enumerate them all here. The brief descriptions and reproductions of drawings of the various reinforcements themselves often illustrate also the general system used throughout a building; and the same may be said of the descriptions of the various systems of concrete floor construction given in Chapter IX.

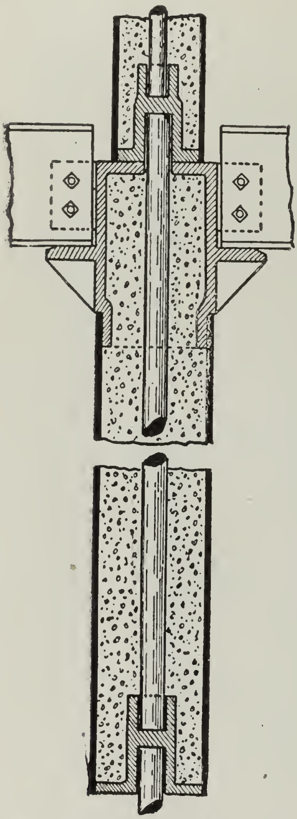


Fig. 544. The T. I. M. Patent Reinforced Column.

The various uses of reinforced concrete are mentioned in Article 525, and the early examples of the same in Article 527. In Chapter II is discussed "concrete capping for wooden piles" in Article 55 and "concrete piles" in Articles 58 to 63. In the same chapter, in Articles 65 to 71, the subject of "reinforced concrete footings" is treated. In Chapter III, in Articles 99 and 100, other references are made to "concrete footings" and to "building laws regarding concrete footings."

The illustrations in the following articles are of various systems of reinforced concrete construction as applied to entire buildings.

592. CLASSIFICATION OF TYPES AND SYSTEMS.—Reinforced concrete building construction, at least that which is used in buildings for commercial purposes, may be broadly divided into two divisions or *types*, (1) "mill" construction in reinforced concrete, and (2) "skeleton" construction in reinforced concrete; and for both of these types various *systems of construction* are employed.

593. MILL CONSTRUCTION IN REINFORCED CONCRETE.—This is similar in many ways to the ordinary mill con-

struction,* the concrete taking the place of the beams, girders, etc., of other materials. "In localities where labor is high and where conditions are more or less congested, it is probably more economical to use brick for walls than to use concrete. In such cases the type of construction is similar to ordinary mill construction. Provision must be made to anchor the beams and girders, which can be done by bending the ends of the reinforcing rods so as to extend horizontally into the wall each side."†

594. SKELETON CONSTRUCTION IN REINFORCED CONCRETE.—This is the type of construction analogous to the so-called "skeleton type" of steel construction. The outside walls may be of any fire-resisting material, such as brick, tile, concrete, etc., and may or may not cover also the concrete columns, piers and girders. There is a skeleton framework of vertical supports and of girders and beams with floor systems of various kinds, and, as in skeleton steel construction, the wall girders and columns carry part of the floor dead and live loads and all of the weight of the outside walls.

When brick facing is used to cover all or part of the outside concrete work, it is usually secured in place by means of galvanized anchors built in the concrete as erected and bonding into the joints of the brick facing.

Concrete panels or curtain-wall panels are usually built after the wooden molds or forms are taken down from the columns, girders, etc., and are set, on the sides, in vertical recesses or grooves left in the sides of the columns as the latter are constructed. These panels are comparatively thin, being often 6 inches and sometimes only 4 inches in thickness. In place of either brick or concrete, hard-burned fire-proofing tile blocks have been used for the filling-in panels, and sometimes brick and tile panels are covered with stucco.

595. AMERICAN SYSTEM OF REINFORCED CONCRETE CONSTRUCTION.—Fig. 545 shows the American system of reinforced concrete construction for short spans, used by the American Concrete Steel Company, Newark, N. J. Plain bars are shown, but any other bars can be used.

* See Chapter VII in "Building Construction and Superintendence, Part II, Carpenters' Work," and also Chapter XXII in the "Architect's and Builder's Pocket-Book," both by Frank E. Kidder.

† Mr. Rudolph P. Miller in Chapter XXIV of the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

596. AMERICAN SYSTEM OF REINFORCING FOR CONCRETE CONSTRUCTION.—Fig. 546 shows a general view of the system of reinforcing used by the American System of Reinforcing for Concrete Construction, Chicago, Ill. The drawing shows the practical application of rods and wire fabric to girders, columns and floor slabs, connections with brick walls, etc. This system is sometimes called the "High Carbon System," from the nature of the steel used.

597. COLUMBIAN SYSTEM.—Fig. 547 shows the general construction of the system used and controlled by the Columbian Fire-proofing Company, Pittsburg, Pa. The Columbian fire-proof floor system was described in Chapter IX, Article 445.

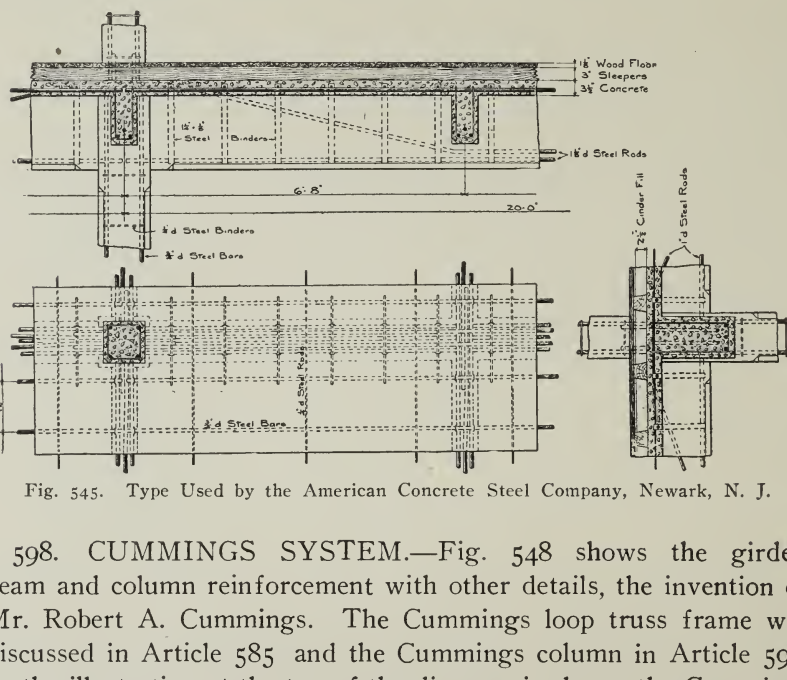


Fig. 545. Type Used by the American Concrete Steel Company, Newark, N. J.

598. CUMMINGS SYSTEM.—Fig. 548 shows the girder, beam and column reinforcement with other details, the invention of Mr. Robert A. Cummings. The Cummings loop truss frame was discussed in Article 585 and the Cummings column in Article 590. In the illustration at the top of the diagram is shown the Cummings method of forming the bent-up bars and attaching them to the tension bars. In general, the plan is to provide tension bars with ends specially anchored, and to securely attach to them small horizontal rods in the middle of the beam or girder, but bent up, as indicated, to pass across the top of the beam and form inclined inverted U-bars or stirrups. The idea is more clearly shown in the

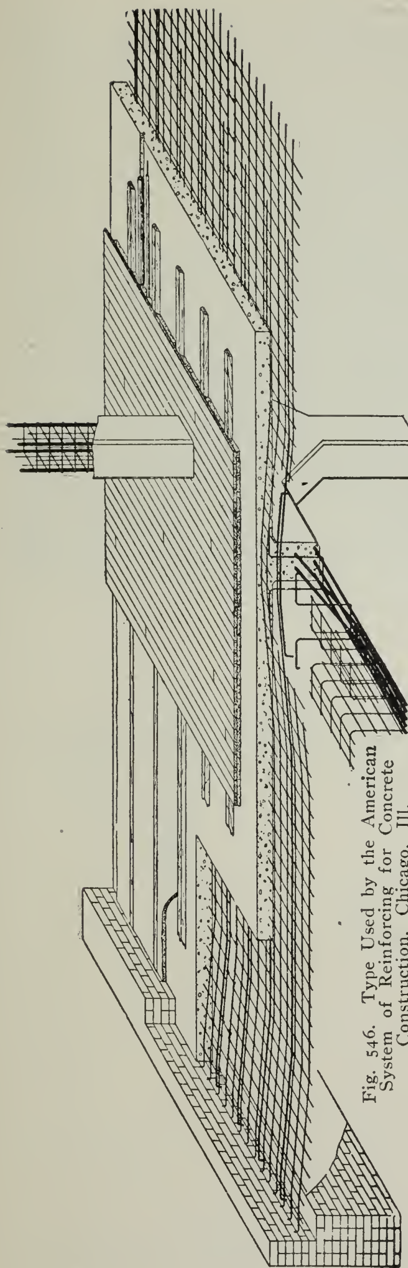


Fig. 546. Type Used by the American System of Reinforcing for Concrete Construction, Chicago, Ill.

sketches below showing the "arrangement of steel." The "supporting chairs," placed at the point of the bending up of the rods, are also drawn. For the slab steel another type of supporting chair is employed, as illustrated in the detail sketch.

The Cummings hooped column is also shown in the upper sketch and the detail of the column reinforcement below. Each hoop is securely attached to the upright rods.

599. CORRUGATED OR JOHNSON BAR REINFORCING SYSTEM. — Fig. 549 shows one of the types of construction used by the Expanded Metal and Corrugated Bar Company, St. Louis, Mo. The drawing shows a typical floor bay in perspective and in section, with the method of constructing and reinforcing the columns, girders, beams and floor slabs of an all-concrete building. The type of construction shown is suitable for spans of more than 14 feet. There are several other types of this particular system suited to various widths of spans, methods of framing, etc. (See also Article 575.)

Fig. 551 shows another system, that of a steel frame with floors of concrete reinforced

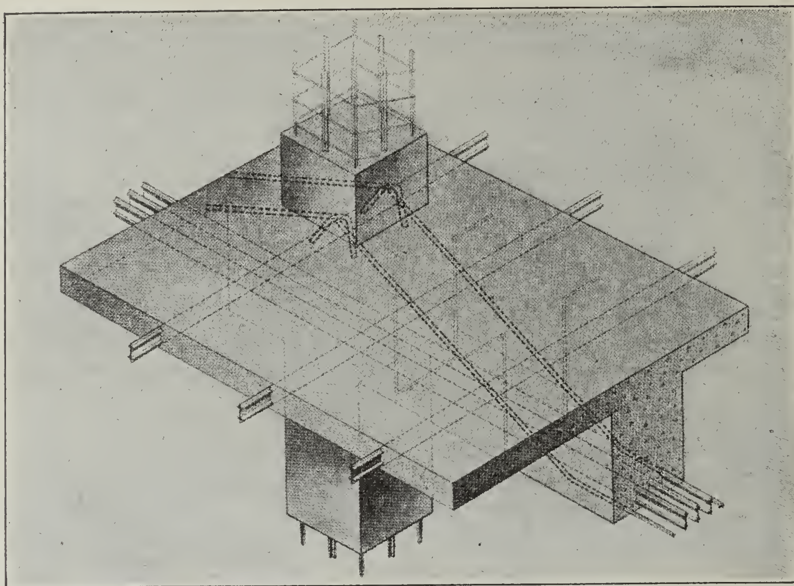


Fig. 547. Columbian System of Reinforced Concrete Construction.

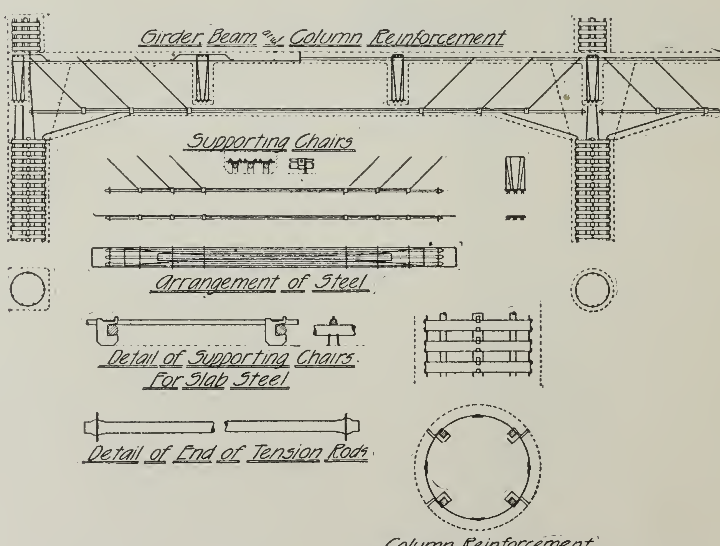
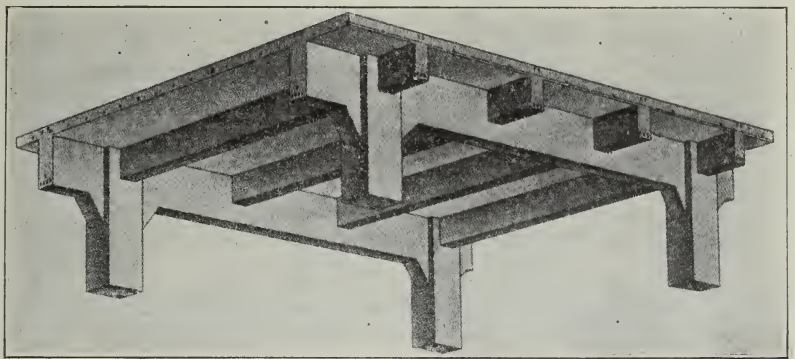


Fig. 548. Cummings System of Reinforced Concrete Construction.

with the Johnson corrugated bars and used in connection with hollow tiles as shown. The upper drawing of the figure shows the longitudinal section through a beam and the lower drawing a transverse section. (See also the Kahn Hollow Tile and Concrete Construction, Article 605, Fig. 557.)

600. EXPANDED METAL AND ROUND BAR SYSTEM. EXAMPLE.—Fig. 550 shows an example of this construction, in



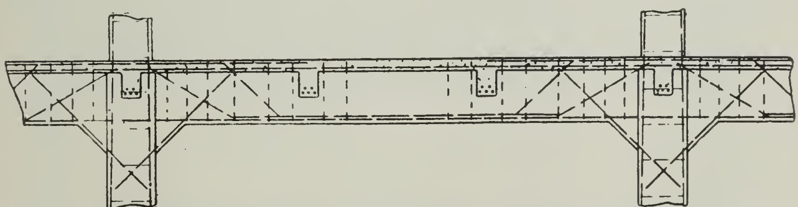


Fig. 549. Corrugated or Johnson Bar Reinforcing System.

a cross-section drawing of the Lynn Storage Warehouse, Lynn, Mass.* Fig. 552 shows details of typical girder, beam and column. Round bars or rods are used for the reinforcement of the girders, beams and columns, while expanded metal forms the slab reinforcement.

601. FABER SYSTEM OF TILE AND CONCRETE CONSTRUCTION.—Fig. 553 shows a system of construction quite similar to that illustrated in Article 599, Fig. 551, and in Articles 602,

* Mr. D. A. Sanborn, Lynn, Mass., architect; Mr. J. R. Worcester, consulting engineer; Eastern Expanded Metal Company, Boston, Mass., designers of the reinforced concrete and contractors for the building. Drawings reproduced through the courtesy of the Atlas Portland Cement Company, New York.

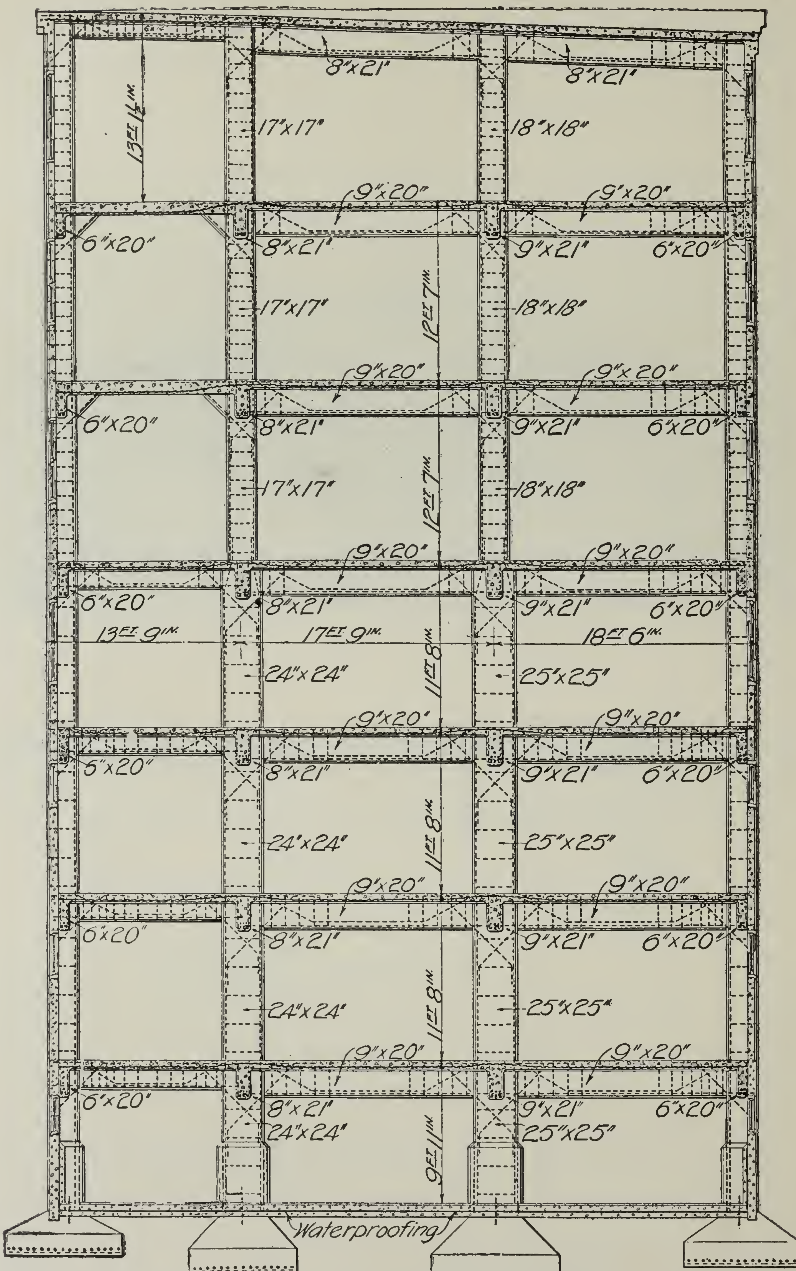


Fig. 550. Cross-section Through Reinforced Storage Warehouse, Lynn, Mass.

604, etc. This system has been extensively used in Europe and was introduced into the United States by the Faber Construction Company, New York, which holds the patents. Unlike some of the other concrete-and-tile systems, however, this construction reinforces the floors longitudinally and transversely, so that the slabs

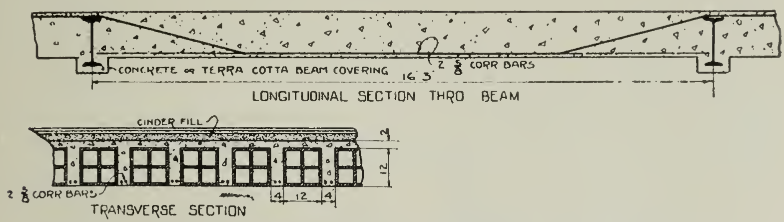


Fig. 551. Combined I-beam, Hollow Tile and Reinforced Concrete System.

have their strength determined as if they were supported on four sides. The concrete, which is a rich mixture of 1 to 3 Portland cement and sand, is kept out of the tile hollows by the tubes of cardboard used as shown; and in figuring compressive

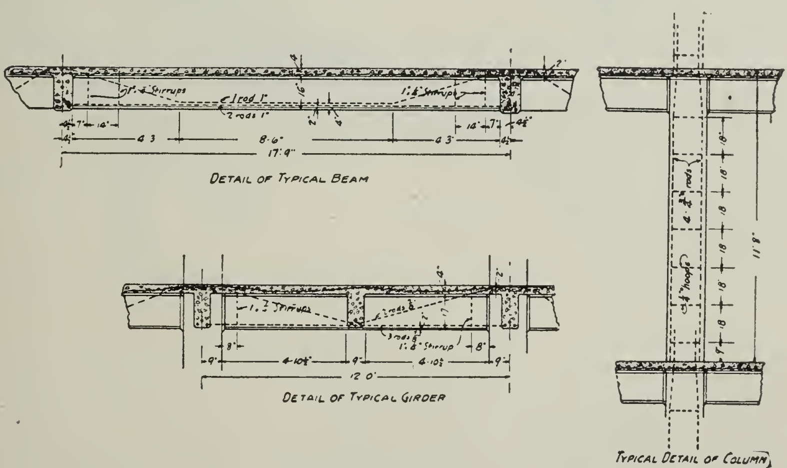


Fig. 552. Beam, Girder and Column Details, Storage Warehouse, Lynn, Mass.

resistance the tiles are assumed to assist in it, as they are made heavier than those for ordinary use.

602. THE GABRIEL SYSTEM OF REINFORCED CONCRETE CONSTRUCTION.—Fig. 554 shows sections of girders, beams, columns and floor slabs for heavy construction used by the

Gabriel Concrete Reinforcement Company, Detroit, Mich., the details being taken from drawings of the W. H. Edgar & Sons Company's sugar warehouse, Detroit, Mich.* This is another example of a combined tile and reinforced concrete floor slab construction.

603. HENNEBIQUE SYSTEM.—Fig. 555 shows a general view of this construction, already illustrated in detail in regard to girder and column reinforcement in Article 581, Fig. 516, and in Article 590, Fig. 531.

604. KAHN BAR COMBINED WITH PLAIN ROD CON-

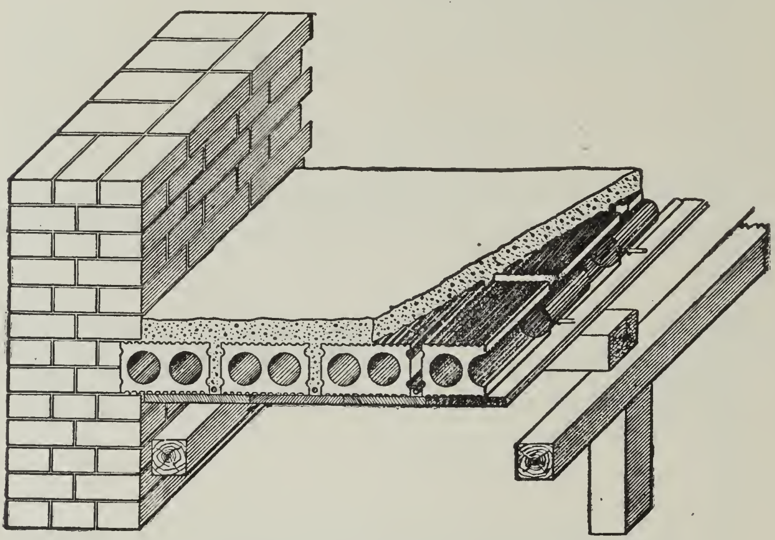


Fig. 553. Faber System of Tile and Concrete Construction.

STRUCTION.—Fig. 556 shows sections through a portion of the building erected by the Lord Baltimore Press, Baltimore, Md.† The steel reinforcement consists of plain round rods for the walls, columns, floor slabs and roof slabs and of Kahn truss bars for beams and girders.

605. KAHN HOLLOW TILE AND REINFORCED CONCRETE SYSTEM.—Fig. 557 shows the Kahn hollow tile and

* Stratton & Baldwin, architects, Detroit, Mich.

† Ballinger & Perrot, architects, Philadelphia, Pa. Courtesy of the architects and William T. Comstock, publisher. See *Architect's and Builder's Magazine*, January, 1908, for description of building.

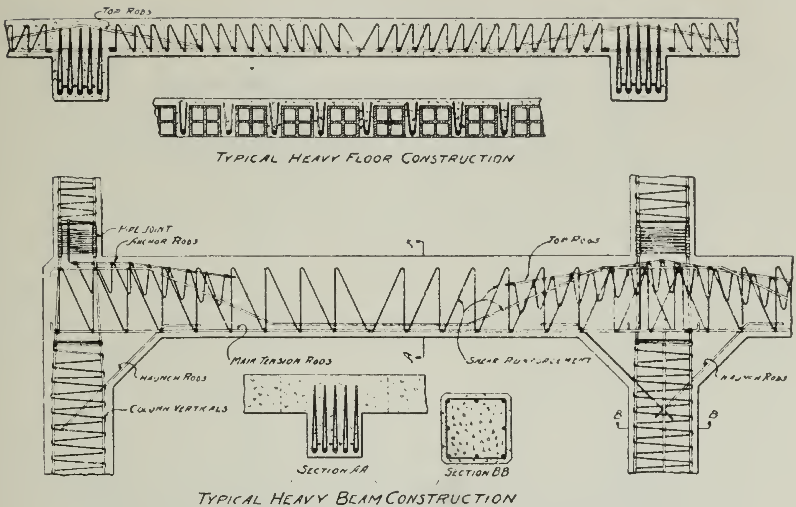


Fig. 554. Gabriel System of Reinforced Concrete Construction.

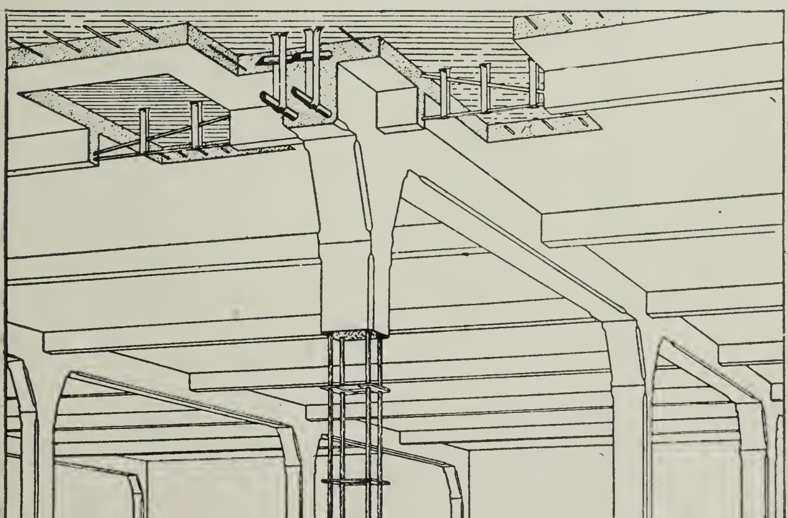


Fig. 555. Hennebique System of Reinforced Concrete Construction.

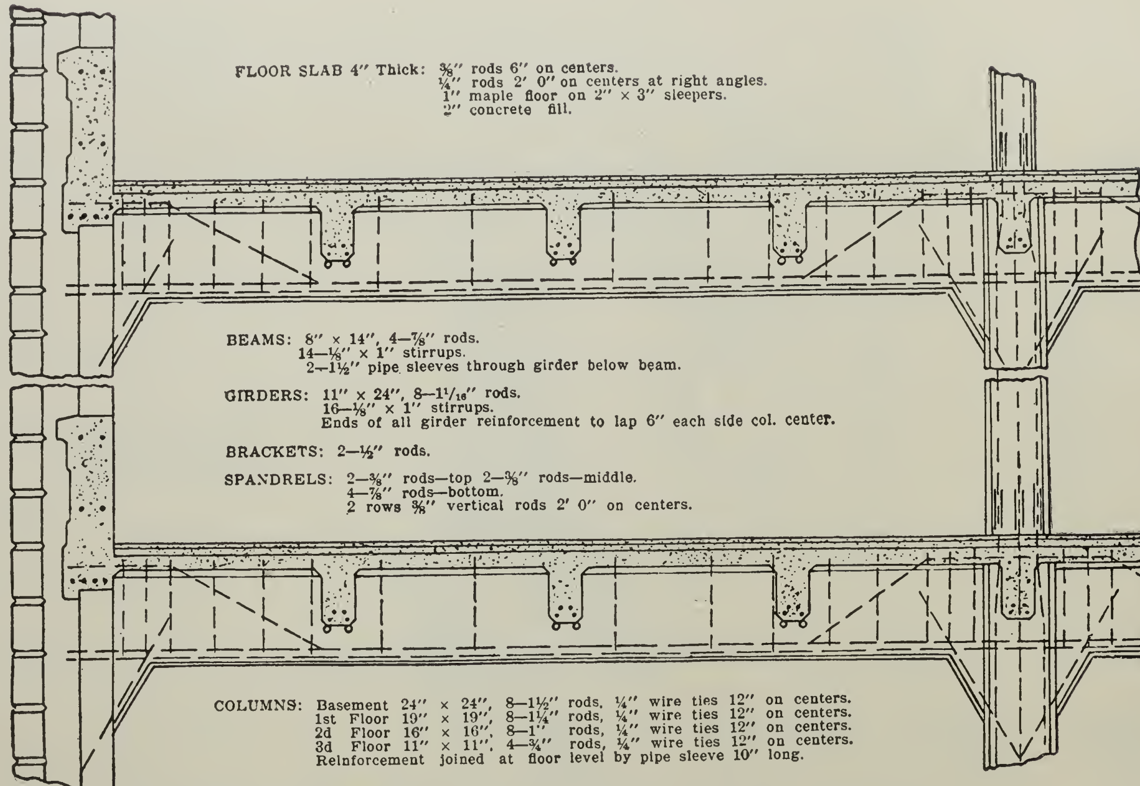


Fig. 556. Sections Through the Lord Baltimore Press Building, Baltimore, Md.

concrete system of construction similar to that illustrated in Articles 599, 601 and 602. (See also Article 582 and Fig. 538.)

Like other similar systems, this consists of a number of reinforced concrete beams separated by spaces, into which the tiles fit. The common form of centering consists of planks, a little wider than the concrete beams, set where the beams are to come above. The tiles are placed in rows with their side edges resting on the planks and form the sides of the concrete beam molds. After the reinforcement is put in position the concrete is poured in, care being used to avoid pushing the tiles out of place. The latter are laid together with as close-fitting end joints as possible. Lath is unnecessary for the ceiling, as it is flat and ready for plaster; and the construction

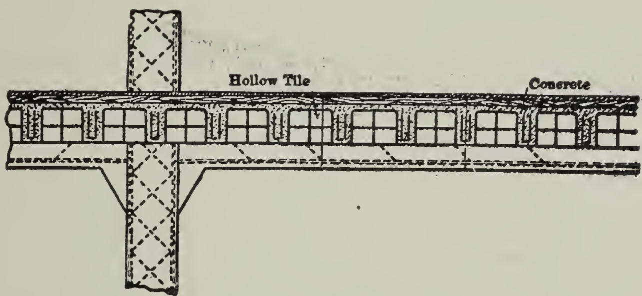


Fig. 557. Kahn Tile and Concrete Construction.

when used in roofs diminishes the amount of condensation on the under surfaces.

606. MERRICK SYSTEM.—This system of reinforced concrete construction, controlled by Mr. Ernest Merrick, New York, has already been described in Chapter IX and illustrated in Figs. 386 and 387.

607. MUSHROOM SYSTEM.—Fig. 558* shows the so-called "Mushroom System," the invention of Mr. C. A. P. Turner of Minneapolis, Minn. This is a flat slab construction, the rods running between the columns both transversely and diagonally as shown in the figure. The construction results in a large column capping. The idea is to do away with all girders and beams and to support the floor slabs directly by the walls and columns.

608. SYSTEM "M." Fig. 559 shows a system of reinforced

* Courtesy of the Atlas Portland Cement Company, New York.

concrete construction introduced by the Standard Concrete Company of New York, and known as "System M."

In this system reinforced concrete floor construction is adapted to the ordinary fire-proof city building, where rapidity in erection is required and where the necessary space for storing materials about the building site cannot be had. In this "System M" a light steel skeleton is erected and the concrete work added in the same manner as for fire-proofing work.

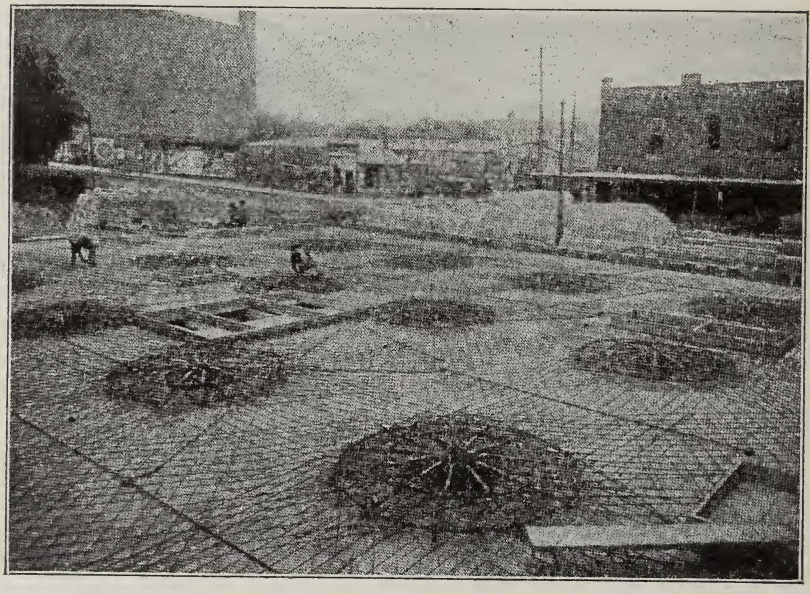


Fig. 558. Mushroom System of Reinforced Concrete Construction.

The light steel frame gives a rigid working floor and materially assists in the erection of the reinforcing work.

The erection of the building proceeds as rapidly as does the erection of all steel and fire-proof construction.

In this form of construction the light framework is inclosed in the concrete in such a manner that the floor members take care of all vertical shear and finally become tension members to the reinforced concrete floors.

Where necessary, steel web members are introduced so that the web stresses are positively transmitted to the chord members.

The columns are designed for gross loads and the rest of the

members of the steel skeleton designed to carry the dead loads of the structure.

One objection to this construction is that the metal shapes which have to be used to obtain the necessary strength do not give a total adhesive resistance proportional to the total amount of metal. Steel used in this way, therefore, is not economical. Another objection is that there is some flexure in the metal shapes used, which tends to disturb the steel and concrete bond.

609. COMPOSITE CONCRETE AND STRUCTURAL STEEL SYSTEMS.—Fig. 560* shows a system of construction

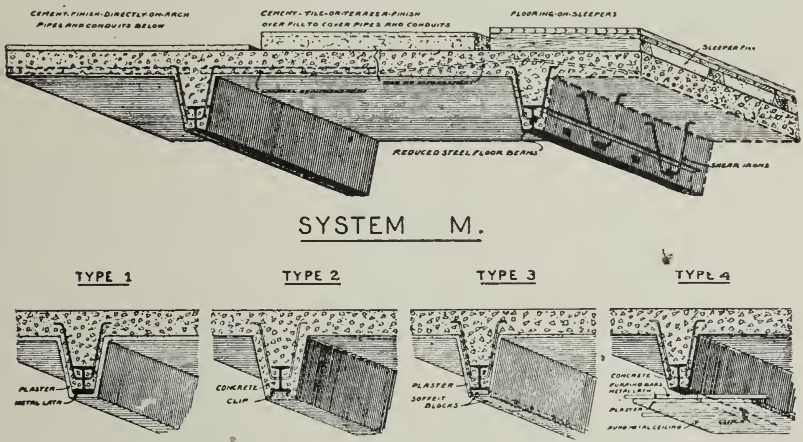


Fig. 559. System "M." Standard Concrete Steel Company.

in which composite columns, combinations of concrete and structural steel are used in connection with reinforced concrete girders, beams and floor slabs.

The following is a brief description of the principal features of the system used in this building:

"One of the problems in concrete building construction, where the loads are heavy or the building is several stories high, is to build the columns small enough to satisfy the requirements of the occupants and owners without overloading the concrete. Its solution is especially difficult in a city building where the land area is so valuable that every square inch of floor-space is at a premium and where there must be more stories than are economical under other conditions. Moreover, the building laws of many cities require more

* The section shown is from the drawing of the design for the plant of the Ketterlinus Lithographical Manufacturing Company, Philadelphia, Pa., Ballinger & Perrot, architects and engineers, Philadelphia, Pa. The drawing is reproduced through the courtesy of the architects and of the Atlas Portland Cement Company, New York.

conservative loading than might be warranted if it were certain that the conditions of construction were in all cases the best.

"In a number of recent instances the difficulty has been met by the use of composite columns, a combination of concrete and structural steel, and this is the plan followed by the designers of the Ketterlinus building. Full details of the column construction are presented in Fig. 560.

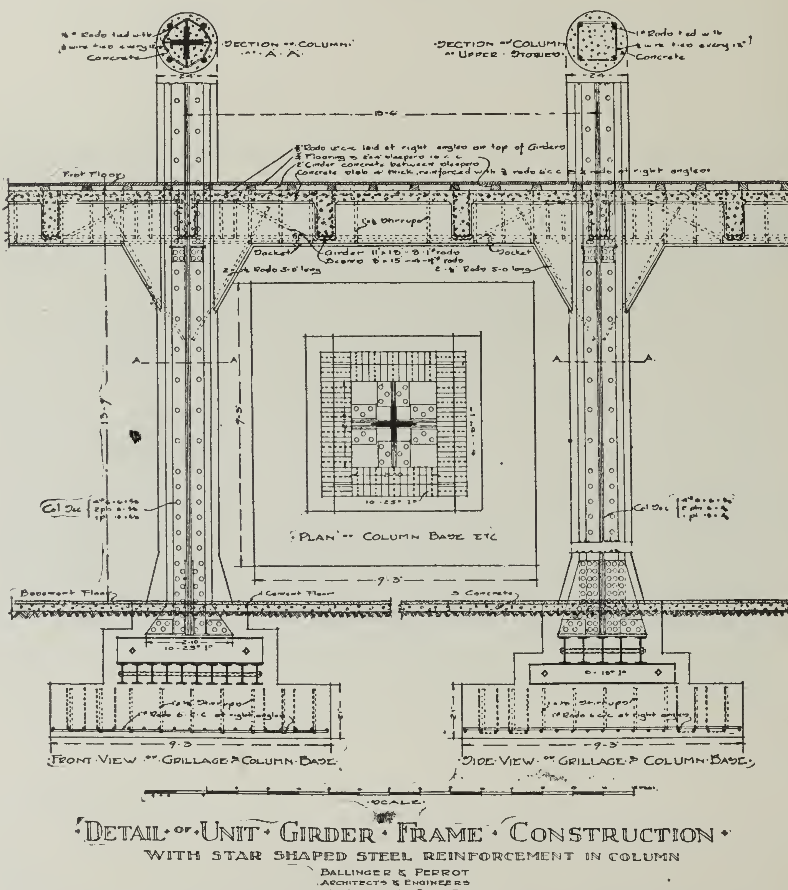


Fig. 560. Section Through a Bay of Ketterlinus Building, Philadelphia, Pa.

"The interior columns in the building up to the fifth floor are 23 inches in diameter. In the basement and the four lower stories the core of the column is formed of steel plates and angle-irons rivetted together in the form of a cross. Around this cross ⅛-inch wire ties were placed every 12 inches and looped around four vertical round rods which increased the reinforcement. In the basement, for example, the center steel is made up of a plate 18 inches wide and ⅝ of an inch thick with two plates of similar thickness, but

of 8-inch width at right-angles to it, and four angle-irons 6 by 6 by ⅝ of an inch, all rivetted together. The four round rods which complete the so-called "Star" reinforcement are 1⅛ inches in diameter.

"The columns in the three stories nearest the top are designed to carry the full dead and live loads of floors and roof. In each lower story the columns are designed to carry the full dead load and a smaller proportion of the full live load than can be carried by the floor construction, this live load factor being reduced proportionately to the number of floors carried. For example, the basement columns were calculated on a basis of carrying, on the steel cores alone, three-fourths of the live load plus the full dead load, with a factor of safety of 4.

"The steel is designed to bear the computed load without exceeding a maximum compression of 16,000 pounds per square inch. The compressive strength of the concrete in these columns is not considered, although it is almost sufficient to carry the dead load.

"The weight of the girders is borne in part by brackets of steel rivetted to the angle-irons and partly by the concrete knees or enlargements of the column which run out obliquely from the columns and which are reinforced on each side by two ½-inch rods.

"Above the fourth story the columns are of the same diameter, but with the more ordinary reinforcement of four round rods.

"To transmit the compressive load from the steel in the columns to the soil, a special design of footing was prepared. A large base was necessary to prevent too great loading of the soil beneath the building, and in order that the pressure from the column might not break or crush the concrete over this large area, a grillage of steel I-beams was placed under each column, as shown in the figure, and the concrete below these I-beams further strengthened against breakage and shear by 1-inch horizontal round rods placed 6 inches apart, and by ¼ by 1 inch stirrups.

"Each girder was designed as an independent beam supported at the ends by the enlargement of the columns and the steel brackets. The area of the reinforcing steel was calculated in the usual way; but instead of placing each rod separately in the form, girder frames were made from quadruple or twin-webbed bars, which were cut, bent to shape and furnished with stirrups fastened to them in the shop. The girder frame reinforcement was brought to the building in the form of a truss, and the work of placing consisted simply of setting this truss in the form upon cast-steel sockets, each having a ¾-inch threaded stud projecting upward through the frame. A nut screwed down on this stud over the frame holds it rigidly in position. This girder frame and socket were the invention of Mr. Emile G. Perrot, one of the firm of architects who designed the building, the object being to insure the exact amount and arrangement of tension and shear members in the exact location as designed, and to afford opportunity for inspection of the steel in position before the pouring of the concrete.

"The rods are rolled in sets of four, connected by a web, and this web is sheared and bent down in 2-inch lengths at intervals of 3 inches, to give

greater grip in the concrete. These 2-inch lengths are bent back over stirrups, where they occur, to clinch them in position on the frame. The outside bars are also cut loose at each end and bent upward to reinforce the top of the beam near the supports. The sockets shown in the figure are shaped so that they support the rods 1½ inches above the bottom of the beam or girder, and are held in place by a ¾-inch bolt passing up through the bottom of the wood mold. These threaded sockets afterward are used for securing shafting, hangers or other fixtures.

"The floor slabs are of usual construction, being 4 inches thick and reinforced for the net span of 3 feet 10 inches with 3-inch No. 10 expanded-metal, this mesh having been substituted in place of ⅜-inch rods spaced 6 inches apart and of occasional ¼-inch rods running in the other direction, as originally shown on the drawings, and at an increase of about 1 per cent of the cost of the building.

"The wearing surface in a 1¼-inch maple floor on 2 by 4-inch sleepers 16 inches apart. These are placed on the concrete slabs and cinder concrete in proportions of 1, 3 and 7 filled in between them.

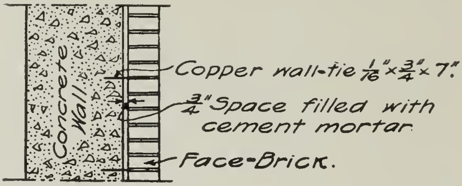


Fig. 561. Brick Facing for Concrete Wall. Ketterlinus Building, Philadelphia, Pa.

"The walls are essentially reinforced concrete columns, veneered on the outside with 4 inches of brickwork and separating the windows. The window lintels are of concrete faced with terra-cotta to match the red sandstone of the older building adjoining and are anchored to the concrete. The lintels form reinforced concrete beams and support a brick wall 13 inches thick, which is run up to the bottom of the terra-cotta window sills.

"The method of connecting the brick with the concrete of the columns is shown in Fig. 561, copper wall-ties 1-16 by ¾ by 7 inches being set in the concrete at intervals, and, after the removal of the forms, bent out and laid into the joints of the face-bricks, which are separated from the concrete by a ¾-inch mortar joint for purposes of alignment."

The reinforced concrete stairs for this building were mentioned in Article 489, and illustrated in Fig. 451 in Chapter IX.

Fig. 562* shows another example of a metal core column designed for tall or heavily loaded buildings, the steel skeleton being incased in the concrete and having the necessary strength to bear

* The figure shows a perspective view of one of the lattice columns with connections for reinforced concrete girders, designed by Professor William H. Burr for the McGraw building, New York City.

the entire load or the greater part of it and resulting in a relatively small total cross-section desirable for the purpose of economizing floor space. The incasing concrete is used merely as a protection from fire and corrosion, and not included in the calculations for the strength of the column, which is designed to bear the entire dead load, but not to be stressed for this load more than is allowed

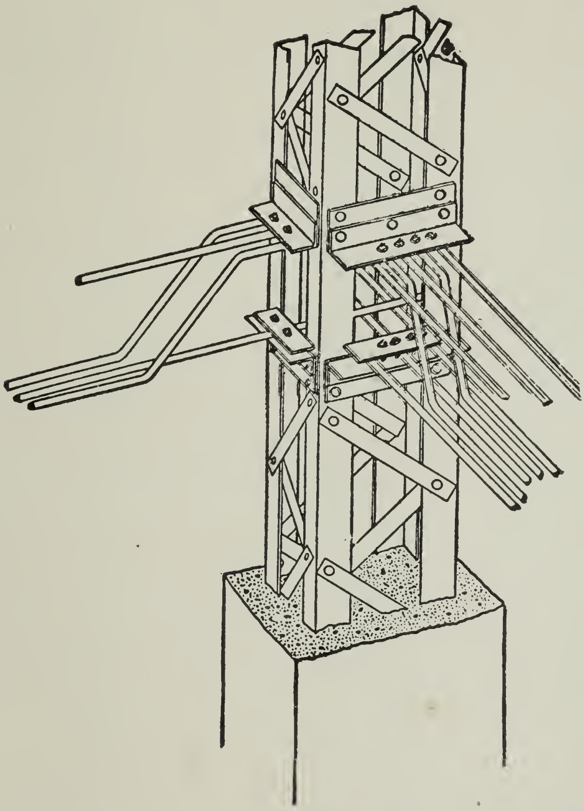


Fig. 562. Metal Core Column, McGraw Building, New York City.

for steel columns by the New York building laws, taking into consideration the ratio of length to the radius of gyration.

In the case of this building the compressive stresses for dead loads were not allowed to exceed 9,000 pounds per square inch. By using such an amount of concrete inside of the steel column framework that 750 pounds per square inch, or one-twelfth of 9,000

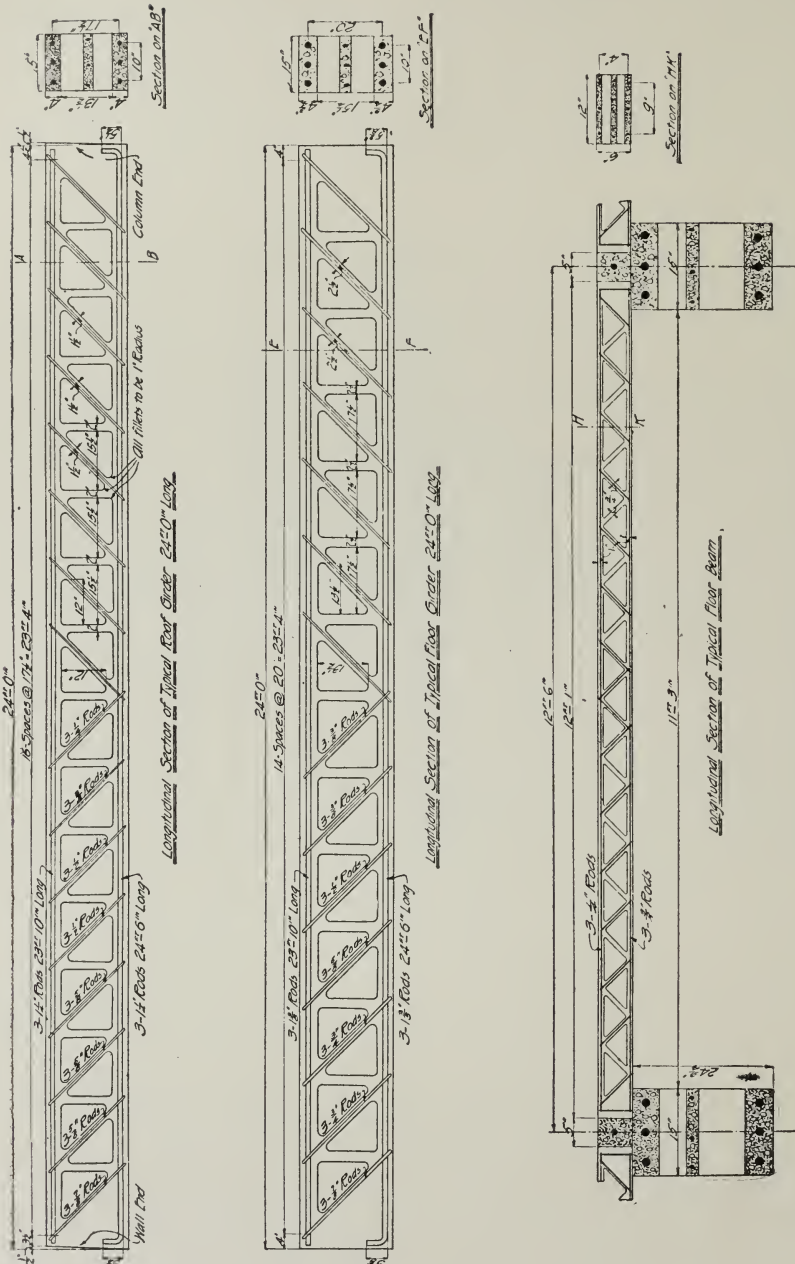


Fig. 563. Visintini Girder and Floor Beams.

pounds per square inch, is the maximum stress on the concrete, the live loads are provided for.

610. VISINTINI SYSTEM.—Fig. 563* shows the details of girders and floor beams of the system invented by Franz Visintini, an architect of Zurich, Switzerland. Although applied in a number of cases in Europe, it was not introduced into the United States until 1904, when it was used in the factory building erected at Reading, Pa., for the Textile Machine Works, by the Concrete Steel Engineering Company, New York, which controls the American patents.

Running across the building from column to column and 12½ feet apart on centers are the large Visintini lattice girders 24 feet long.

In ordinary design these would be connected by floor beams spaced 6 or 8 feet apart, with slabs between the beams. The Visintini system, however, permits the slabs and floor beams to be laid as one; that is, after placing the girders, the floor beams are laid from girder to girder, but close together so as to form a floor slab of themselves.

The details of a typical floor girder, roof girder and floor beam are shown in Fig. 563. The girders have their members arranged like those of a Pratt truss, a common type used in steel bridges; and the computations of stresses are made as in bridge design. The bottom chord consists of a slab of concrete reinforced with 3 round rods to take all of the tension, and the top chord in compression is similarly reinforced. The vertical web members, which are in compression, are of plain concrete, while the diagonals are each reinforced for tension with rods whose ends are attached to the rods of the top and bottom chords.

The floor beams are only 6 inches thick and 12 feet 5 inches long; and these, as stated above, form the slab also, being placed close together. The girders are designed and computed as Warren trusses with all of the web members inclined 45°, half of them in tension and half in compression.

One of the chief advantages of this type of construction is in the method of molding the beams and girders so as to reduce the cost of the forms. In this particular case the work was greatly facil-

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* Courtesy of the Atlas Portland Cement Company, New York.

itated because the building was erected in winter. The beams, of which there are about 2,900, were molded on the ground in an adjacent building. The proportions for the beam concrete, based on cement loosely measured, were one part of Portland cement to one part of sand to three parts of stone screenings. The floor beams weigh only 480 pounds each.

The cores, which were oiled before placing, were pulled a few hours after the pouring, and the side and bottom forms were left on for two days, when the beams were hard enough to move. After setting from 10 to 30 days longer, as needed, they were carried to the building and raised in place. They were run on to the first floor of the building, and then raised by a platform elevator through an open bay to the floor where they were required.

Two of the floor beams were tested to destruction and broke under a load of pig-iron weighing 342 pounds per square foot. The building is designed for a safe working load of 75 pounds per square foot.

The girders weigh about three tons each, and were molded upon the floor immediately underneath their final position; so that they required only to be hoisted into place, a distance of 14 feet. This was done by means of a special derrick and two strong hoists.

The proportions were: one part of Portland cement (measured loosely), 1½ parts of sand and 3½ parts of broken trap rock passing through a 1⅜-inch ring.

To tie the columns together across the building, the floor beams were placed with a 5-inch opening between their ends, and this space was filled with concrete in which was imbedded a rod, as shown, just above the cross-section of the girder in the lower drawing of the figure.

6. PROTECTION OF REINFORCED CONCRETE CONSTRUCTION.

611. GENERAL CONSIDERATIONS.—The protection of reinforced concrete construction includes protection against fire and protection against corrosion.

612. PROTECTION AGAINST FIRE.—The fire-resisting properties of concretes in general were discussed in Chapter IX, under "Fire-proofing Materials," and in this chapter in Article 507; and the kinds of concrete used in reinforced work in Article 558.

The concretes considered in reinforced concrete work in questions of fire-resistance are the stone and gravel concretes, as cinder concrete, although very useful when fire-proofing is the primary consideration, is unreliable in regard to strength.

The principal considerations involved in the fire-proof character of concrete are non-conductivity and loss of strength.

Several series of tests have been made to determine the conductivity of various concretes subjected to different temperatures. Among others the reader is referred to some tests* recently made by Professor Woolson of Columbia University, New York City.

From 2 to 2½ inches of concrete covering will protect reinforcing metal from injurious heat for the period of any ordinary conflagration, provided that the concrete stays in place during the fire and that the reinforcing metal exposed to the fire does not convey by conductivity an injurious amount of heat to the imbedded portion. Gravel concrete in reinforced work is not considered a safe or reliable fire-resisting aggregate.

In regard to loss of strength, it has been found that all concrete mixtures when heated throughout to a temperature of from 1,000° to 1,500° Fahr. lose a large proportion of their strength and elasticity; and this fact must be borne in mind in designing.

Tests have been made to determine the effects of extreme heat upon concretes, and the reader is referred to an excellent summary† of the results obtained and reported by Professor Woolson of Columbia University, New York City.

Recent tests made by city authorities, notably those of New York and Philadelphia, and the great conflagrations in Baltimore and San Francisco, have afforded opportunities for observing the effect of fire on reinforced concrete construction of various kinds.

The artificial tests show that "to a depth averaging about one inch the concrete is seriously impaired and is easily washed off by a hose stream applied to the surface. Any stone containing an appreciable percentage of carbonate of lime will calcine and cause failure. Where the construction is poorly designed, allowing an excessive deflection, the fine cracks in the concrete below the steel

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* See *Engineering News*, August 15, 1907, p. 168, and the "Architect's and Builder's Pocket-Book," Frank E. Kidder, Chapter XXIV.

† See Proc. Am. Soc. Testing Materials, Vol. VI, pp. 443, 446 and 448. See also Tables VIII and IX, Chapter XXIV, the "Architect's and Builder's Pocket-Book," Frank E. Kidder.

will open to such an extent as to allow the heat to reach the metal reinforcements. When the reinforcement is such as to produce a plane of weakness in the concrete there is liable to be a flaking off of concrete and a consequent exposure of metal."*

A report of a committee of engineers, investigating the effects of great heat on concrete construction in the fire following the San Francisco earthquake in 1906, gives the following summary:

"Concrete floors generally had hung ceilings, and, where thus protected, were uninjured. Where exposed, the concrete is in most cases destroyed, as, for instance, in the Sloan, Rialto and Aronson buildings and in the Crocker warehouse. The concrete is dry, and while in many cases hard, yet all the water has been burned out and it may be said to be destroyed, even if able to support weights. Floor coverings of wood invariably burned, adding to the destruction. Sleepers were generally burned. Surfaces of cement mortar fared much better, the linoleum covering remaining practically intact." †

Mr. A. L. A. Himmelwright concluded, after an examination of the ruins of the buildings in San Francisco, that, as a fire-resisting construction, reinforced concrete is inferior to any type of steel construction with concrete floors and concrete column and girder protection, but superior to steel construction with terra-cotta floor and terra-cotta column and girder protection. He states that "where this method was used a very slight attack of fire was generally sufficient to cause the rupture of the concrete underneath the reinforcing metal, so that it fell away, exposing the metal. There were comparatively few buildings, however, in which this method of construction was used."‡

In regard to the thickness of concrete required, "from a study of the tests and fires above referred to, a fair conclusion as to the amount of protection against fire would seem to be: In all columns, in large and important girders, trusses or other supports, at least two inches of concrete outside of all reinforcement; in girders and beams and slabs of long spans, about one and one-half inches of concrete outside of all reinforcement; in stair work, floor slabs

* See also résumé of results of and conclusions from tests and conflagrations by Mr. Rudolph P. Miller in Chapter XXIV, the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

† Proc. Am. Soc. C. E., March, 1907, p. 330.

‡ Proc. Am. Soc. C. E., August, 1907, p. 668.

(short span), walls and partitions, from three-quarters to one inch of concrete outside of all reinforcement.

"In footings and foundations the thickness of concrete outside of reinforcement should be at least three inches. Not for fire protection, but for protection against corrosion."*

613. PROTECTION AGAINST CORROSION.—Experiments have been made to determine the extent of the corrosion of reinforcing metals in reinforced concrete of different kinds and mixtures, and much has been recently written on the subject.

Professor Charles L. Norton, of the Massachusetts Institute of Technology, Boston, Mass., draws the following conclusions as the result of experiments and tests made during the years 1902 and 1903:†

In these experiments the steel was encased in concrete one and one-half inches thick on all sides.

(1) Steel imbedded in neat cement is secure against corrosion.

(2) Steel imbedded in a dense concrete mixture is safe against corrosion.

(3) To assure a thorough coating of the steel the concrete should be mixed wet.

(4) Porous concrete, allowing the admission of moisture, will not protect the steel thoroughly.

(5) A coating of rust is not a protection against further corrosion, as has been sometimes claimed.

From these conclusions it would appear that the steel of reinforced concrete is secure against corrosion, provided that it is thoroughly imbedded in concrete and that a slight coating of rust on the steel, where imbedded, does no harm, as the cement is strongly alkaline, counteracts the acidity of the iron oxide and prevents further corrosion.

On the question of the corrosion of steel in cinder concrete, Professor Norton concludes: "There is one limitation to the whole question, that is, the possibility of getting the steel properly incased in concrete. Many engineers will have nothing to do with concrete because of the difficulty in getting 'sound' work. This is especially true of cinder concrete, where the porous nature of the

* Mr. Rudolph P. Miller, in Chapter XXIV, of the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

† See Reports Nos. 4 and 9, Insurance Experiment Station, Boston Manufacturers' Mutual Fire Insurance Company.

cinders has led to much dry concrete, many voids and much corrosion. I feel that nothing in this whole subject has been more misunderstood than the action of cinder concrete. We usually hear that it contains much sulphur and that this causes corrosion. Sulphur might cause corrosion, if present, were it not for the presence of the strongly alkaline cement; but with the latter present the corrosion of steel by the sulphur of cinders in a sound Portland cement concrete is the veriest myth; and, as a matter of fact, the ordinary cinders, classed as steam cinders, contain only a very small amount of sulphur. There can be no question that cinder concrete has rusted great quantities of steel; not because of its sulphur, but because it was mixed too dry, through the action of the cinders in absorbing moisture, and because it contained, therefore, voids; and secondly, because in addition to the above conditions the cinders often contained oxide of iron which, when not coated over with the cement by thorough wet mixing, caused the rusting of any steel which is touched. There is one cure and only one: mix wet and mix well. With this precaution I would trust cinder concrete quite as quickly as stone concrete in the matter of corrosion."*

7. ERECTION OF REINFORCED CONCRETE CONSTRUCTION.

614. GENERAL CONSIDERATIONS.—The process of erection of reinforced concrete buildings has some details in common with that of the erection of buildings of ordinary construction. In other details, however, the procedure is quite different. The following are about the usual steps in about the order in which they are taken:

(1) The general preparation of the site of the building and the excavation.
(2) The laying of the foundations for walls, piers, etc.
(3) The erection of the molds or forms.
(4) The mixing of the concrete.
(5) The placing of the metal reinforcements.
(6) The depositing and ramming of the concrete in the molds or forms and around the reinforcements.
(7) The removal of the molds or forms after the concrete has set.

* See Report No. 9, Insurance Experiment Station, Boston Manufacturers' Mutual Fire Insurance Company.

(8) The finishing of the concrete surfaces.

(9) The finishing or laying of the floor and roof surfaces.

(10) The testing of the completed structure.

Details (3) to (7), inclusive, are successive steps in the process of erection, which are progressive. That is, for example, (5) and (6) may be going on one story, while (3) is going on in a story above, (7) in a story below and while (4) is going on all the time.

For the inspection of reinforced concrete construction the utmost competency and thoroughness are absolutely essential. The best designs and materials are of no avail if the work is improperly done.

1. An inspector or superintendent needs especially the following qualifications:

(1) Familiarity with the nature and qualities of the materials.
(2) Knowledge of the principles of reinforced concrete design.
(3) Activity and alertness in seeing that the work progresses properly.
(4) Watchfulness to see that proper tests of the materials are made as the work goes on.

2. The inspection itself includes, especially, in addition to the details already mentioned:

(1) Great care in thoroughly joining new to previously laid and partially set concrete.
(2) The thorough cleaning out of forms and molds before the pouring in of the concrete.
(3) The thorough and complete filling of all parts of molds.
(4) The placing of all reinforcements in the exact position they should occupy.

The above summary of the details pertaining to the erection of reinforced concrete structures is all that can be attempted in this book. Most of the details have already been generally discussed in the preceding divisions of this chapter in connection with concrete work in general.

For detailed discussions and illustrations of various reinforced concrete buildings to be used for different purposes, the reader is

referred to the many recent treatises on this particular branch of masonry building construction and superintendence.

4. CEMENT AND CONCRETE BLOCK CONSTRUCTION.

615. INTRODUCTORY.—While concrete and artificial stone has been made and used for centuries, it is only recently that the manufacture and use of concrete building blocks have rapidly developed. The recent growth of the use of concrete blocks and of machines for making them has been one of the most rapid in the whole cement trade. Beginning its development about the year 1900, the industry has grown until there are now (1908) hundreds of patents in machines and blocks and thousands of manufacturers of the blocks themselves.

The following are some of the steps, in order, in the early history of the manufacture of and use of cement and concrete blocks:

(1) Concrete molded into separate blocks, used as bricks or blocks of stone, and used and introduced in the early part of the 19th century.

(2) Solid concrete blocks used at first, but found to be too heavy.

(3) Hollow blocks used and left hollow in the walls, or filled with concrete after being placed there. Such blocks patented in England, in 1875, by Sellers.

(4) Concrete facing slabs manufactured soon after 1875 and made with projections for securing them to the concrete filling.

(5) Blocks made in Z-shape and set so as to make hollow walls. These were patented by Listh, of Newcastle, in 1878, and were made by pouring wet concrete into the molds and leaving it there many hours before removal.

(6) Modern rapid methods, American inventions, by which hollow concrete blocks are molded from semi-wet mixtures of a consistency that allows an immediate removal from the molds, and by which the manufacture of the blocks has been greatly simplified and cheapened, developed from about 1900.

There is a growing demand for the material, and no doubt its use would have been much more general had it not been for very numerous poor results, both constructive and artistic, due to misinformation and inexperience on the part of some manufacturers, builders and so-called designers.

It has been said with truth that in no department of the cement industry has the need of standard specifications and uniform instructions been so great as in the manufacture of cement and concrete building blocks.

616. RELATIVE ADVANTAGES OF CONCRETE BLOCKS.—Concrete blocks are manufactured in factories equipped with suitable molds and appliances for making and thoroughly curing them and are then brought to the building and set in place. Thus the main portion of the expense in connection with plain concrete walls built in place, that is, the construction of the forms and the handling of the concrete, is avoided. The use of materials for veneering, common in some of the better classes of concrete buildings, is also unnecessary.

Another great advantage is in the use of shapes which result in hollow walls; that is, blocks with one or more hollow spaces, or blocks of such shape that their combination in a wall produces hollow spaces in it.

617. USES OF CONCRETE BLOCKS OR CEMENT BLOCKS.—Some of the particular uses to which cement blocks or concrete blocks are put are the following:

(1) Foundations for various kinds of superstructures.

(2) Retaining-walls.

(3) Exterior walls carrying loads.

(4) Interior walls carrying loads.

(5) Fire-walls and partitions.

(6) Curtain-walls, exterior and interior.

(7) Filler blocks for floor slabs.

(8) Veneering of walls.

(9) Cornice, trim and ornamental work.

(10) Chimney flues, etc., etc.

There are increasing demands for these blocks for still other uses, and cities are beginning to recognize them as legitimate building materials and to formulate requirements which must be satisfied when they are used.

618. MATERIALS FOR CONCRETE BUILDING BLOCKS.—The *size of the aggregate* used is generally relatively small, the gravel or stone not exceeding from ½ to ¾ inch in size. At least one-third of the material, by weight, should be coarser than ⅛ inch, and blocks made of such gravel or screenings and mixed in the proportion of 1 to 5 give as good results as if made in the proportion of 1 to 3 with sand only.

Coarse fragments do not show on the surface when the mixing is thorough.

Sand and *gravel* are generally the cheapest materials for concrete block work.

If thoroughly mixed, a *small* percentage of *clay* or *loam* does no harm.

Stone screenings, when of good quality, result in as strong concrete as results from sand and gravel, and make blocks of a somewhat lighter color.

Cinders are occasionally used for block work. They do not develop great strength, but may serve for some purposes.

Lime in the form of dry-slaked lime or "hydrate lime," added to block concrete, in the proportion of ¼ to ½ of the cement used, gives it a lighter color and makes the blocks denser and less liable to be permeated by water.

Portland cement is the cheapest cement for a given strength in concrete block-making and is the only hydraulic material used to any large extent for this kind of work. It is uniform, strong and prompt in hardening, and gains as great strength in air as in water.

619. PROPORTIONS OF MATERIALS FOR CONCRETE BUILDING BLOCKS.—In adjusting the proportions of materials for concrete building blocks, the most important considerations are strength, permeability, appearance and cost.

Although mixtures poor in cement, such as 1 to 8 or 1 to 10, may have strength enough, they are extremely porous. Again, a poor mixture strong enough for a building may not be strong enough to stand rough handling when in the form of blocks at the factory. Strength and hardness depend also upon the character of other materials for a given proportion of sand.

Experience seems to teach that blocks of satisfactory quality cannot be made by hand-mixing and tamping under ordinary fac-

tory conditions from a poorer mixture than 1 to 5; and, for good results, even this proportion requires properly graded sand and gravel or screenings, plenty of water and thorough mixing and tamping. With coarse mixed sand only the proportion should not be less than 1 to 4. Good blocks cannot be made with fine sand alone without making the cost prohibitory on account of the amount of cement necessary.

These 1 to 5 and 1 to 4 mixtures are more or less porous, according to the character of the grading of the screenings or gravel used; but the porosity can be reduced by putting in some hydrated lime to replace a part of the cement. This lime makes the wet mixture more plastic, more easily compacted by ramming and gives a lighter color to the blocks.

The following mixtures* have been recommended for concrete blocks, the term "gravel" meaning "a suitable mixture of sand and gravel, or stone screenings, containing grains of all sizes, from fine to ½-inch sizes:"

1 to 4 Mixtures, by Weight.

Cement 150, gravel 600.
Cement 125, hyd. lime 25, gravel 600.
Cement 100, hyd. lime 50, gravel 600.

1 to 5 Mixtures, by Weight.

Cement 120, gravel 600.
Cement 100, hyd. lime 20, gravel 600.

The *proportion of water* is an important matter and affects greatly the quality of the work. Free water should flush to the surface when the concrete is tamped, and the mixture should be what is called a "quaking" mixture.

620. MIXING THE CONCRETE.—Thorough manipulation of the concrete mixture is very important. The concrete may be mixed by hand or by power-mixers, and the latter may be of the continuous type or may be batch-mixing type. Power-mixing results in a quality of product and in a uniformity superior to that resulting from hand-mixing. Of the power-mixers the batch-mixers, operated by steam, gasoline engine or electric motor, are better adapted to concrete block work than are the power-mixers of the continuous type. There are several types of both continuous and batch power-mixers.

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* S. B. Newberry, in "Concrete Building Blocks," Bulletin No. 1, Association of American Portland Cement Manufacturers, Philadelphia.

However mixed, initial set must be prevented by regulating the size of batch to capacity of machine, so that no cement will be wet longer than thirty minutes.

621. THE SHAPE OF CONCRETE BLOCKS.—As has been stated before, one great advantage in using concrete block construction is the opportunity it offers of obtaining hollow walls.

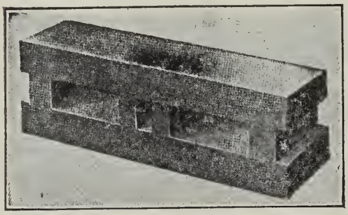


Fig. 564. Concrete Block with Four Webs and Three Air-spaces.

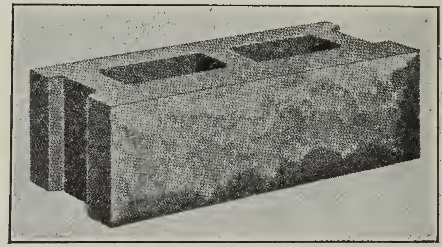


Fig. 565. Concrete Stretcher Block. Three Webs and Two Air-spaces.

The principal advantages of hollow walls over solid walls may be given as follows:

(1) Insulation against heat and cold.
(2) Saving of material.
(3) Greater resistance to the passage of water and dampness.
(4) A general ventilation of wall spaces and adjoining rooms through the pores of the hollow concrete blocks, and a consequent elimination of sweating on the inside of walls.

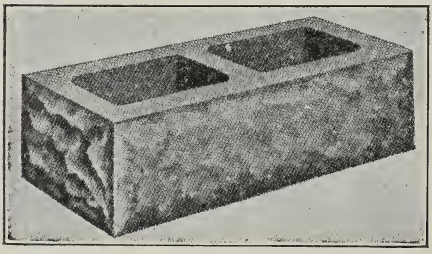


Fig. 566. Concrete Corner Block. Three Webs and Two Large Cores.

Fig. 567. Concrete Stretcher Block Faced with Lafarge Cement.

It is important to notice that the great saving due to the omission of material from the interior of walls, and the consequent profit to the manufacturer and reduction in cost to the consumer, is accompanied by sanitary advantages.

622. BLOCKS WITH FOUR WEBS AND THREE AIR-SPACES.—Fig. 564 shows an early form of hollow block, used in many buildings, and a type still followed by many manufacturers. There are four transverse webs, one at either end and two midway of the block. The form lends itself to the use of the essential half blocks, which can be made without change of cores; and to L-shaped corner blocks which result in a better corner construction than that obtained by butting the end of one block against the side of another.

623. BLOCKS WITH THREE WEBS AND TWO AIR-SPACES.—Fig. 565 shows a stretcher block of this type with small cores. Fig. 566 shows a three-web corner block with large cores,

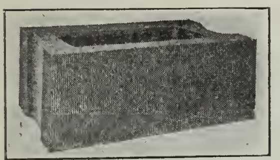


Fig. 568. Concrete Block. Single Air-space.

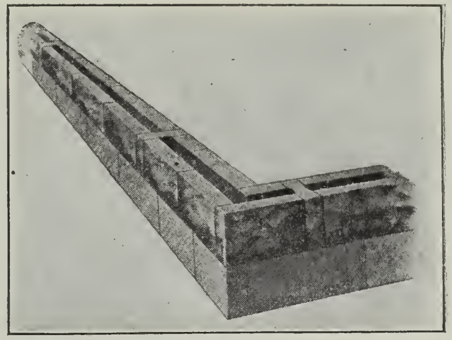


Fig. 569. Hollow Wall of Solid Concrete Blocks. Block Ties.

and Fig. 567 shows a stretcher block of ordinary Portland cement faced with Lafarge cement.

The type of blocks shown in this article seems to be the one most used, judging by the number of different machines turning out blocks belonging to it.

624. BLOCKS WITH ONE AIR-SPACE.—Fig. 568 shows the average type of single air-space block, the middle web being omitted and only one core being required. This is a newer and less common form than that shown in Figs. 565, 566 and 567. Some of the advantages of this type of concrete blocks are a lessening of the tendency of moisture penetration during heavy rains because of the smaller number of cross-partitions; better opportunities for thorough tamping around one core than around two or more, and, in consequence, for a more thoroughly and uniformly compacted

product; less difficulty in releasing the blocks and removing the cores; less danger of tearing the blocks; and a slight saving in materials.

625. SOLID BLOCKS FOR HOLLOW WALLS.—Fig. 569 shows solid concrete blocks used to build a two-piece wall with air-space, the inner and outer portions being tied or bonded together by header blocks crossing the air-space as shown.

Fig. 570 shows a two-part concrete hollow wall built of solid concrete blocks, the two parts of the walls being tied together with metal ties laid in the mortar joints.

In other attempts to combine the one-piece and the two-piece

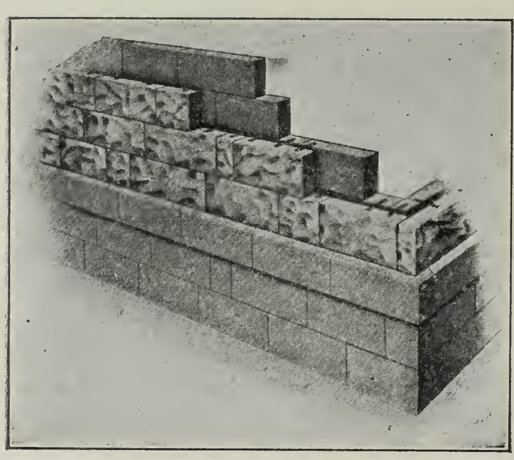


Fig. 570. Hollow Wall of Solid Concrete Blocks. Metal Ties.

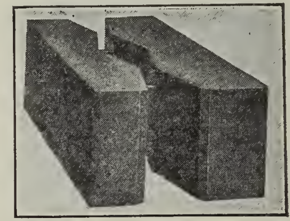


Fig. 571. Solid Concrete Blocks. Metal Ties, Imbedded.

forms, solid slabs of concrete have been united by metal rods or ties, the ends of which are imbedded in the inner and outer slabs. The slabs of concrete are sometimes brick-shape or solid-block-shape, with all faces rectangular, and are sometimes made with irregular horizontal cross-sections.

Fig. 571 shows one form of such blocks, the two slabs of concrete being tied together with four ¼-inch galvanized-iron rods imbedded in the block during its manufacture. Common dimensions of the block shown are: height, 8 inches; length, 24 inches; and depth in the wall, from 8 to 16 inches.

The object of systems of blocks such as are shown in Figs. 570

and 571 is to secure a continuous air-space of approximately uniform cross-section throughout the wall.

Those who advocate this type of hollow wall concrete block construction refer to the use of metal with concrete in reinforced work. Those who criticise it as faulty construction reply that the metal in reinforced concrete is completely imbedded and protected from rust and corrosion, while the metal ties of the connected concrete blocks are for the greater part without such protection, and liable to rust from the moisture penetrating the outside blocks and to deterioration from atmospheric action.

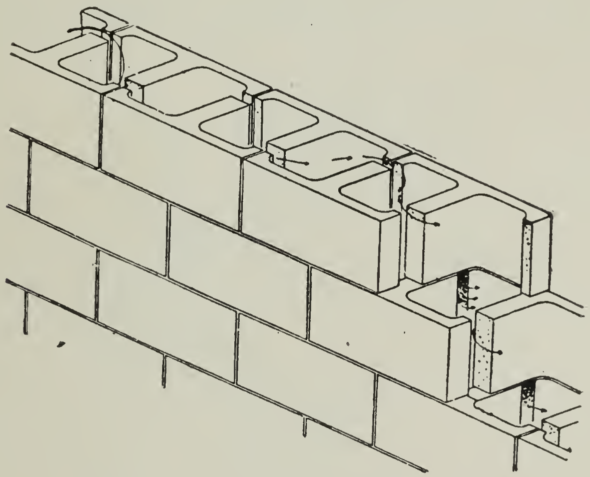


Fig. 572. Two-piece Hollow Concrete Wall.

626. TWO-PIECE CONCRETE BLOCKS.—In 1902, in an effort to overcome some of the difficulties of manufacture met with in making one-piece blocks, the so-called "two-piece blocks" for hollow concrete walls were introduced. Fig. 572 shows a portion of a wall constructed of these blocks and indicates clearly the bond and the continuous air-space. The shape of the blocks is such that those forming the outer face bond with those forming the inner surface by the overlapping of projections in alternate courses. The blocks are T-shaped, with short reinforcing arms at either end of the face section, and they break joint not only between courses,

but also laterally or transversely in every course, leaving no vertical joints extending through the wall.

This form of concrete block also results in advantages in regard to convenience in manufacture. Interior cores are not needed in the manufacture of one-face blocks, which can thus be made under direct and instantaneous pressure without the use of a tamper.

The manufacturers of these blocks, and also some engineering authorities, claim that these processes "permit of the use of as large a percentage of water as may be necessary to fulfil the requirements of standard engineering specifications for a medium or quaking mixture, and at the same time allow the use of as large size aggregate as may be desired;" and that "thus, not only is a much more thorough crystallization secured in the initial set

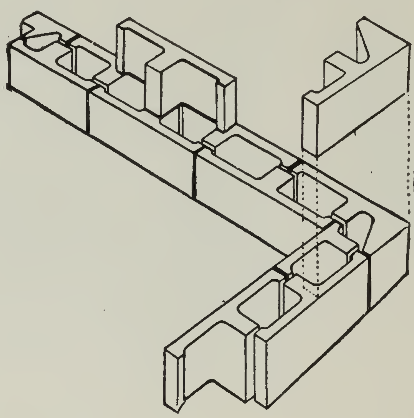


Fig. 573. Two-piece Concrete Blocks. Corner Construction.

than is possible with a dry mixture, but far greater strength and density are obtained than can be possibly in a sand and cement mixture."*

Fig. 573 shows the method of constructing a corner, with corner blocks, bond, broken joints, etc.

Fig. 574 shows an adaptation of two-piece blocks to "multiple air-space" construction, by which an interlocking bond is obtained. By varying applications of the same principle, resulting in the use of a still greater number of members, walls may be built of any

* See "Concrete-block Manufacture, Processes and Machines," by Harmon Howard Rice, Chapter VIII, "Shape of Blocks."

desired thickness, and for any special requirements, such as those of cold-storage plants, ice-houses, etc.

Fig. 575 shows these blocks adapted to the backing of a brick-veneered wall, and Fig. 576 shows them used for the backing of walls faced with blocks of stone, concrete, terra-cotta or any other material. The veneering materials are tied to the concrete backing blocks with metal ties laid in the mortar joints and thin veneers

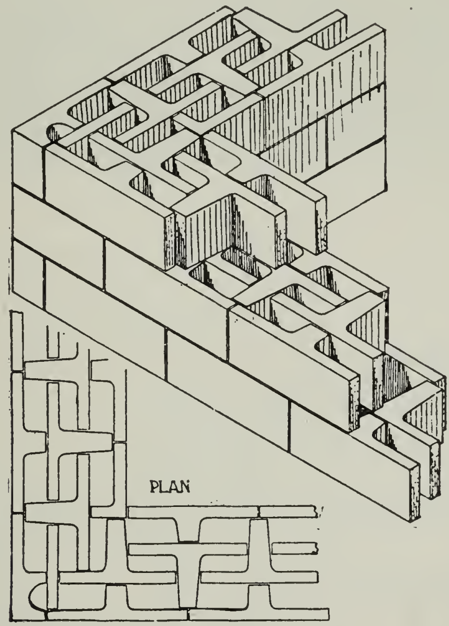


Fig. 574. Two-piece Concrete Blocks. Multiple Air-space.

carry none of the weight coming upon the walls, the backing being of great strength. A hollow-dry wall results, impervious to moisture and resistant to the transmission of heat.

Fig. 577 shows some details of hollow concrete wall construction in which these two-piece blocks are used with various modifications and adaptations to suit special requirements. The notations in the drawings* shown indicate clearly the varying details of the construction.

* Courtesy of the American Hydraulic Stone Company, Denver, Col., the manufacturers of these blocks by the Ferguson System of Concrete Construction.

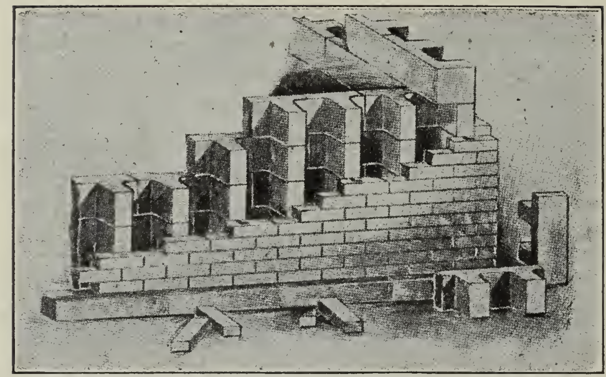


Fig. 575. Two-piece Concrete Blocks Used as Backing for Brick-veneered Wall.

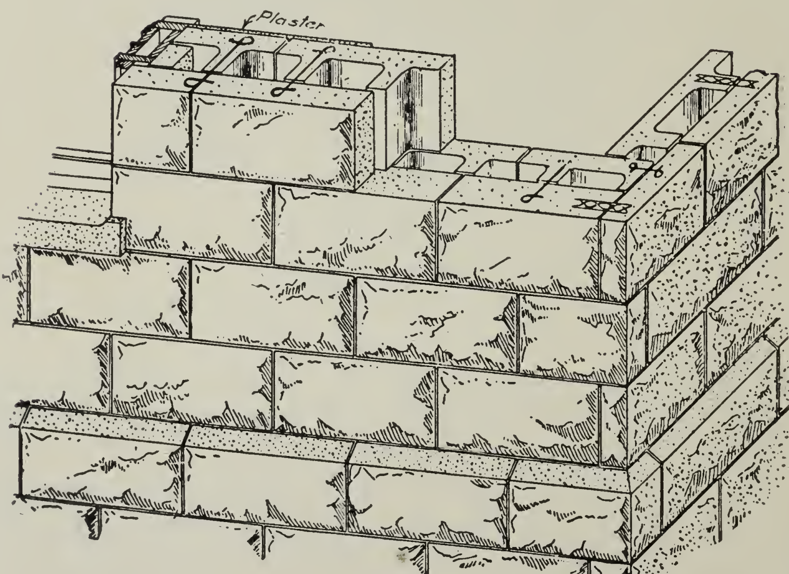


Fig. 576. Two-piece Concrete Blocks Used as Backing for Stone or Concrete.

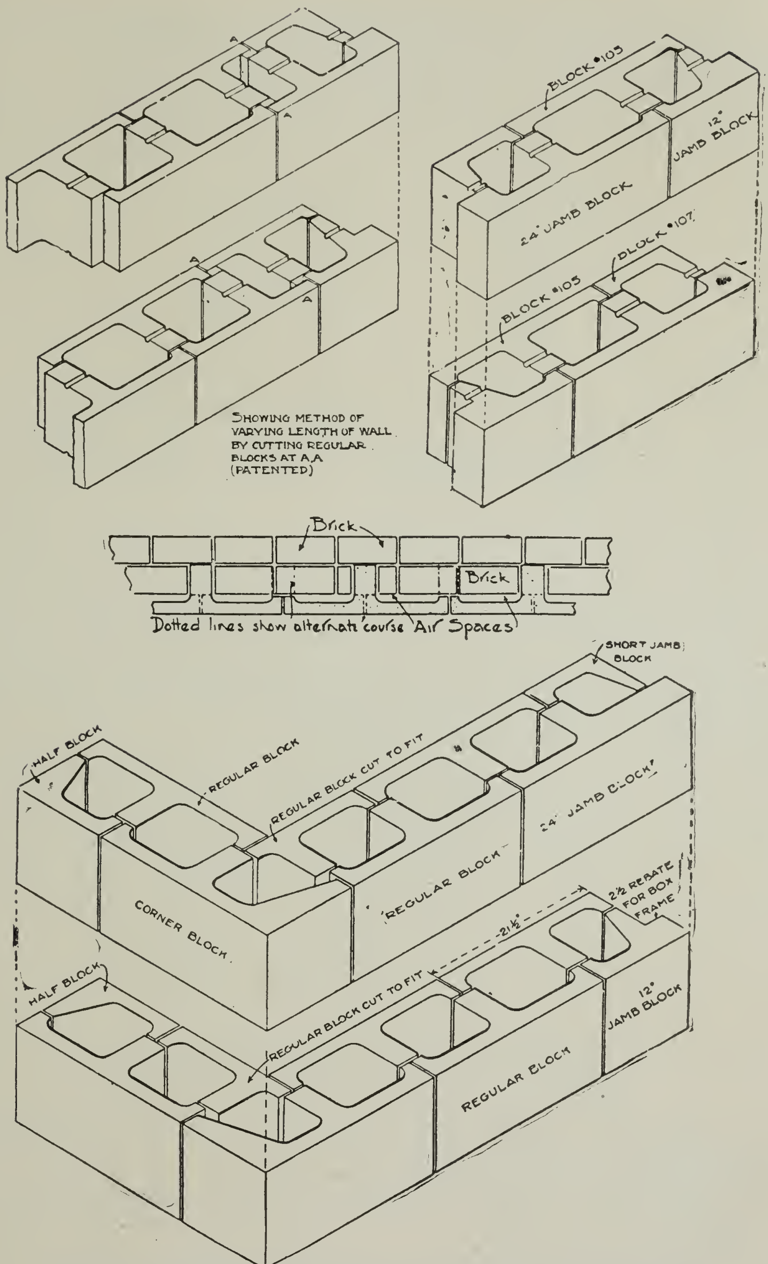


Fig. 577. Two-piece Concrete Blocks. Details of Wall Construction.

Fig. 578 shows the method employed in supporting wood floor joists and in anchoring them to the concrete wall blocks.

Fig. 579 shows one method of constructing wall flues.

In regard to the *strength* of the blocks described in this article,

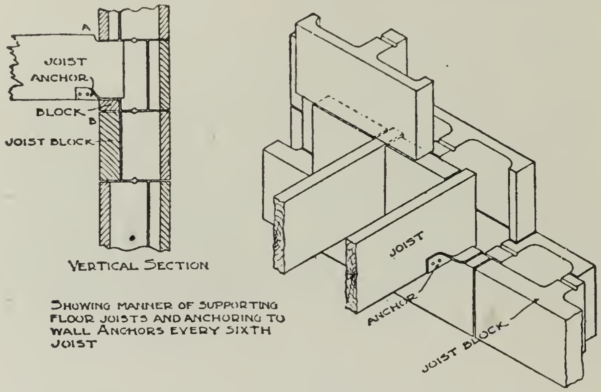


Fig. 578. Two-piece Concrete Blocks. Joist Supports.

tests of single blocks, 21 days old, 12-inch by 24-inch for 12-inch walls, set on edge on a plank and unsupported in any way, were made at the Allis-Chalmers Works, Milwaukee, Wis., showing a crushing strength of 2,600 pounds per square inch. The blocks for this test were selected at random.

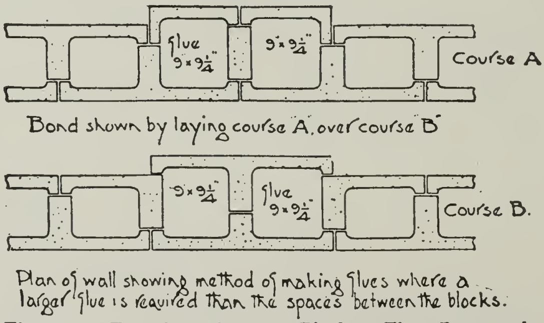


Fig. 579. Two-piece Concrete Blocks. Flue Construction.

The average *weight* of the blocks varies from 34 to 60 pounds, depending upon the width of the wall.

The *width* of walls or similar constructions may vary from 5¾ inches up to any width.

There is an average of 50 *per cent of air-space,* the percentage increasing with greater widths of walls.

Facing.—Where a block is to be faced the mold is filled with a 1 to 7 or 1 to 10 mixture of coarse concrete, a quarter of an inch is raked out of the top of the mold and this space filled with face matter mixed 1 to 2½ or 1 to 3 of fine sand and cement. The entire mass is then compressed at once, giving a hard face of great density, which does not tend to crack nor to peel off, as is more apt to be the case with faces trowelled on after a block is made.

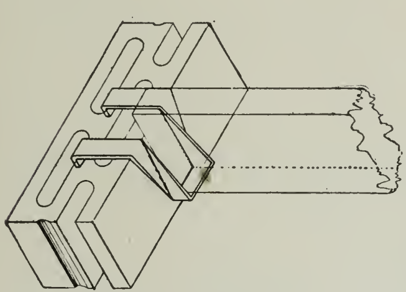


Fig. 580. One-piece Concrete Block. Staggered Air-spaces.

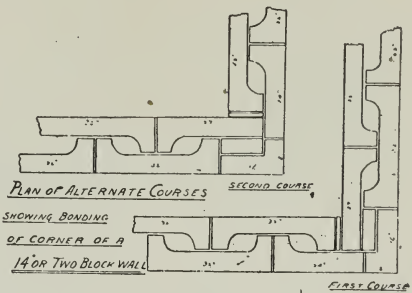


Fig. 581. Angular Concrete Blocks. Fourteen-inch Wall.

627. ONE-PIECE BLOCKS WITH STAGGERED WEBS AND SPACES.—With the idea of arranging the transverse webs and air-spaces so that every web is backed by an air-chamber and so that, consequently, no portion of the solid concrete connects directly the outer with the inner face of the wall, a one-piece concrete block has been put upon the market, differing in form and principle from those already described.

This type of block is illustrated in Fig. 580,* which shows clearly the construction. In the example given one method of joist or beam support is shown also, the spaces in the block being used as anchorages for the joist or beam hangers.

The section of this block is such that the passage of moisture is made difficult and reduced to a minimum. These blocks have been used extensively and have given general satisfaction.

628. SPECIAL AND MISCELLANEOUS TYPES OF CONCRETE BLOCKS.—It is impossible here to even enumerate the many different-shaped blocks and the many varying details in all the various systems used.

In the general principles of the number of air-spaces and in the

* Courtesy of the Miracle Pressed Stone Company, Minneapolis, Minn.

continuity of same, some systems are quite similar to those already described, but vary in detail of shape of block and shape of air-space.

Figs. 581 and 582, for example, show the general arrangement of so-called "angular block" construction,* in which the blocks have the general shape of angles, channels and tees, and can be made of any thickness so as to provide for air-spaces of any size and for walls of any thickness.

Fig. 581 shows two adjoining courses of a 14-inch or two-block wall with method of bonding at corners; and Fig. 582 shows the same for an 18-inch or three-brick wall.

Figs. 583 and 584† show walls built on the two-wall system with E-shaped concrete blocks, each block being reinforced in the continuous portion with bent galvanized-iron wires, of sizes varying

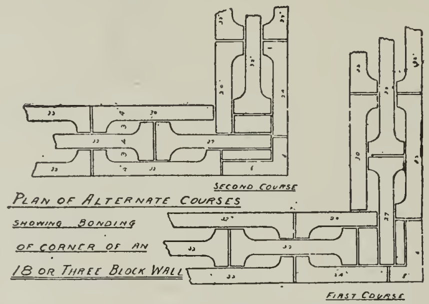


Fig. 582. Angular Concrete Blocks. Eighteen-inch Wall.

from No. 9 to No. 12. Fig. 583 shows the E-shaped blocks set against cement brick backing and tied to same with wire wall ties laid in the mortar joints. Fig. 584 shows both divisions of the hollow wall built of the E-shaped blocks. A sufficient space is left between the two divisions to insure a continuous horizontal as well as a continuous vertical air-space.

The metal reinforcement has been found especially efficacious in lintels, caps, sills under concentrated loads, etc., and also in blocks in preventing cracks from the loading.

In the special examples given the walls rest on a solid concrete foundation, between which and the blocks is placed a damp-proof course of slate.

* Courtesy of the Fisher Hydraulic Stone and Machinery Company, Baltimore, Md.
† Courtesy of Mr. W. A. Schenck, engineer of the National Prison and Vault Engineering Company, Washington, D. C.

A sufficient number of examples have been given to illustrate the principal types of concrete block wall construction, and for further and complete details in any particular case the manufacturers' catalogues should be consulted.

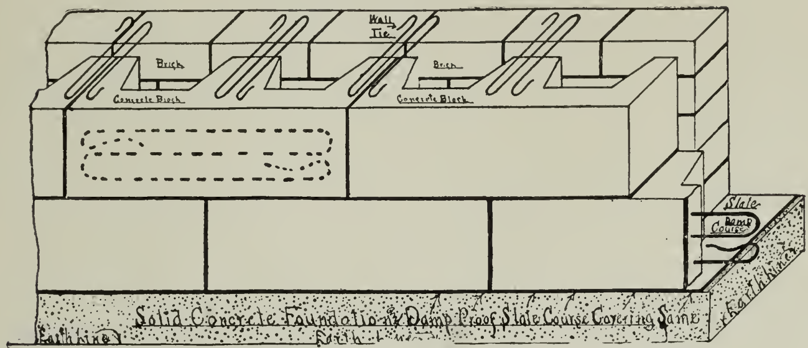


Fig. 583. Reinforced Concrete Blocks. Cement Block Backing.

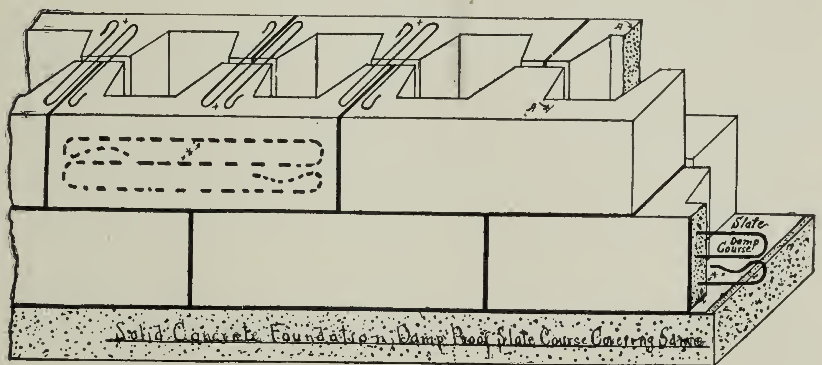


Fig. 584. Reinforced Concrete Blocks. E-shaped Backing Blocks.

629. PROCESSES USED IN CONCRETE BLOCK MANUFACTURE.—There are six different processes employed in making concrete blocks, as follows:

(1) The hand-tamping process.
(2) The pneumatic tamping process.
(3) The process of pouring into iron molds.
(4) The process of casting in sand.
(5) The mechanical pressure process.
 (a) Hand pressure.
 (b) Power pressure.
(6) The hydraulic pressure process.

Differences of opinion regarding the superiority of any one over another of these processes have led to unlimited contentions; but it seems to be the opinion of a majority of engineers and architects that a more dense and homogeneous block can be obtained by mechanical pressure processes than by any other.

630. FACING AND ORNAMENTATION.—Mixtures generally used for facing concrete blocks in their manufacture vary from 1 and 1 to 1 and 3. Those used for the backing or the body of the blocks vary from 1 and 4 to 1, 3 and 4. The manner of applying the facing and casting it with the body to make a unit and avoid a line of cleavage varies with the kind of machine used.

The color of the facing depends upon various details of materials, mixing, added ingredients, etc., such as the color of the cement, sand and screenings, the purity of the water, and the color of the pigments, when used. Colors produced by artificial means usually fade in time, and unfading colors can be produced only by the use of aggregates of the desired shade.

A nearly water-tight face may be obtained by the use of fine sand and a large proportion of cement, or by the use of waterproofing compounds.

The form of the face and the architectural or ornamental treatment depend upon the good or bad taste of the designer and upon the corresponding form of the particular plates used in the actual manufacture of the blocks.

631. MACHINES AND MOLDS FOR CONCRETE BLOCK MANUFACTURE.—These may be conveniently divided into three groups, as follows:*

"(1) Machines and molds for manufacturing blocks by tamping a dry mixture, using a comparatively fine aggregate.

(2) Machines for compressing in molds, without tamping, a medium-wet mixture, using an aggregate graded from fine to coarse.

(3) Molds for forming blocks by pouring a wet mixture."

The objects of a concrete block mold or machine are:

"(1) Means for enclosing the mass during formation into the desired shape and size.

(2) Means for properly and quickly compacting the mass.

* "Concrete Block Manufacture, Processes and Machines," by Harmon Howard Rice.

(3) Means for giving desired variation to exposed surfaces.

(4) Means for making a face of texture differing from the body of the block.

(5) Means for rapid discharge of the product.

(6) Means for preventing injury to the block while green."

It is not possible here to describe various types of machines and processes of manufacture, and the reader is referred for detailed information to excellent books on the subject, such as the one by Mr. Rice, referred to in the footnote of this article, and also to the complete descriptive and illustrated catalogues furnished by the manufacturers.

632. DETAILS OF BUILDING CONSTRUCTION.—When concrete blocks are used for the *foundation walls* below grade they are usually started upon footings of solid and wet concrete of proper width and thickness for the weight carried and for the soil built upon. If the walls are thin care must be taken to divide up long horizontal lengths by means of cross-walls or by occasional pilaster piers.

Joist and Girder Supports.—The methods vary with the system of blocks used. Sometimes the joists run into the walls, necessitating narrow courses of blocks outside the ends of the joists and small blocks for filling in between, as indicated in Fig. 578; and sometimes the joists are hung and anchored by joist-hangers, as shown in Fig. 580.

A few courses of solid concrete blocks must be used under concentrated loads when the factor of safety is not high enough with the area of concrete of the hollow construction. Instead of using solid blocks, the material of the hollow construction is sometimes reinforced for greater strength, as shown in Figs. 583 and 584.

Thickness of Walls.—Many cities are now incorporating in their building laws regulations for concrete block construction, and in such cases the architect and builder simply follow the requirements. The thickness of walls required for basement and superstructure are usually the same as for brick walls, and where city ordinances for this construction do not prevail, for all ordinary work the thicknesses 8, 10, 12 and 15 or 16 inches may be safely used, 10 and 8 inches being used for first and second stories of a two-story build-

ing, 12, 10 and 8 inches for a three-story building, and 15, 12, 10 and 8 for a four-story building.

When used for *partitions,* concrete blocks are usually made 4 inches thick for non-bearing partitions and 6 inches thick for bearing partitions.

Metal wall-plugs, such as are described in Article 361 and shown in Figs. 209 and 212, are the most convenient appliances for use in *fastening the trim* to the walls, the plugs being inserted in the mortar joints between the blocks.

Different Shapes for Constructive Details.—Various shapes are made in all systems of concrete block construction for use in special detailed parts of buildings, such as arches, door-jambs and window-jambs, angles and corners of walls, lintels, sills, band-courses, etc.

Manufacturers' catalogues give full information regarding such details. But the only way to advance the legitimate use of concrete blocks in architectural work is to stop the practice of using stock sizes and stock patterns and of adapting design and construction to some particular make of blocks or machines. It has been said, with much truth, that unless the block makers are prepared to make blocks to fit the designs of architects, the block makers will finally have to go out of business.

633. BUILDING REGULATIONS FOR CONCRETE BLOCKS.—In many of the larger cities regulations giving the requirements for this kind of construction have already been carefully formulated and incorporated into the building codes.

Some of these building ordinances relating to concrete block construction show exhaustive study and care in their preparation, and the reader is referred to Chapter XIII, "Specifications," for some of these regulations.

CHAPTER XI.

Iron and Steel Supports for Masonwork. Skeleton Construction.

634. INTRODUCTORY.—Although constructions of iron and steel do not properly come within the scope of this volume, there are so many places where metalwork is used in connection with brick, stone and terra-cotta that it has been thought desirable to briefly describe the most common forms of iron and steel construction used for supporting masonry walls, and the various minor details of metalwork used in connection with the masonwork.

635. GIRDERS AND LINTELS.—All openings in masonry walls which it is not feasible to span with arches should have iron or steel lintels or girders to support the masonwork above. The objections to wooden beams for supporting masonwork are given in Article 361.

Since the price of rolled steel has been so greatly reduced, girders and lintels for supporting brick and stone walls are almost universally formed of steel I-beams or girders built up of steel plates and angle-bars. Except for very wide spans and exceptionally heavy loads, steel I-beams may be most economically used for such supports. As a rule, at least two beams should be used to support a 9-inch or 12-inch wall, and three beams for a 16-inch wall, the size of the beams, of course, depending upon the weight to be supported. The beams should be connected at their ends, and every 4 or 5 feet between, with bolts and cast-iron separators, cast so as to exactly fit between the beams. The girders should have a bearing at each end of at least 6 inches, and should also rest on cast-iron bearing-plates of ample size.

If the wall to be supported is of brick, the first course above the girder should be laid all headers. The width of the girder is generally made 2 inches less than that of the wall. In calculating the weight to be supported by a girder, much depends upon the structure of the wall above. If the wall is without openings, and does

not support floor beams, only the portion of the wall included within the dotted lines, Fig. 585, need be considered as the portion supported by the girder. The beams composing the girder in that case, however, should be made very stiff, so as to have little deflection. If there are several openings above the girder, and espcially if there is a pier over the middle of it, as shown in Fig. 586, then the manner in which the weight bears upon it should be carefully considered. In a case such as is shown in Fig. 586 the entire dead weight included between the dotted lines *A A* and *B B* should be considered

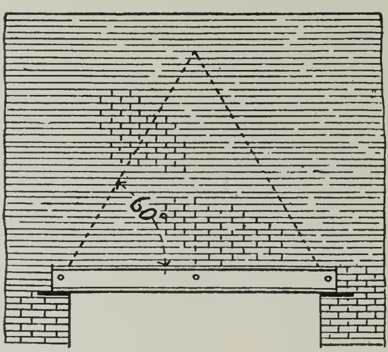


Fig. 585. Amount of Brickwork Supported by Girder.

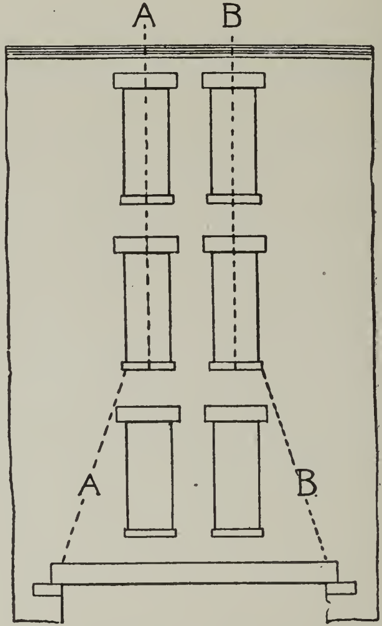


Fig. 586. Openings over Girder. Amount of Brickwork Supported.

as coming on the girder, and proper allowance made for a concentration of the greater part of the load at the middle point of the span.

When beams are used to support an entire wall, running under its entire length, and when the wall is longer than sixteen or eighteen feet, the whole weight of the wall should be taken as coming upon the beams; because, if the beams bend, the wall will settle and have a tendency to push out the supports and to cause the entire structure to fall.

Steel lintels for supporting stone or terra-cotta caps and flat arches are described in Article 280.

636. CAST-IRON LINTELS.*—Lintels of cast-iron were at one time extensively used for supporting brick walls over store fronts and door openings, and even at the present time are used to some extent. On account of the brittle character of this metal, however, and of its low tensile strength, it should not be used for beams subjected to moving loads, such as loads coming from floors upon which heavy articles are moved.

Cast-iron beams of long span are not as economical as those made of rolled steel. About the only places, therefore, in which cast-iron lintels may be suitably and economically used are those over store fronts where the span does not exceed 8 feet, and those over door openings in unfinished brick partitions where a flat head

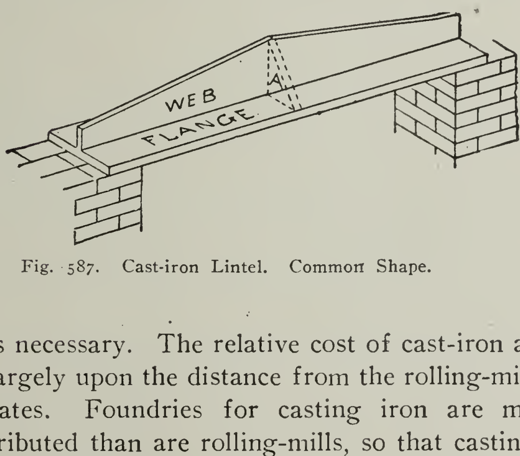


Fig. 587. Cast-iron Lintel. Common Shape.

Fig. 588. Cast-iron Lintel. Two Webs.

is necessary. The relative cost of cast-iron and steel lintels depends largely upon the distance from the rolling-mills and upon the freight rates. Foundries for casting iron are much more widely distributed than are rolling-mills, so that castings of almost any shape can usually be obtained in any city of twenty thousand inhabitants; while mills for rolling steel beams are comparatively few in number, and most of them are located in the extreme eastern portion of the country.

The common shape for cast-iron lintels over door openings is that shown in Fig. 587. The width of the flange is usually made the full thickness of the wall, and the extreme height of the lintel at the middle of the span is not less than two-thirds of nor greater than the width of the flange. The strength of the lintel may be

* The reader is referred to Kidder's "Architect's and Builder's Pocket-Book," Chapter XVI, "Strength of Cast-iron, Wooden and Stone Beams," for a discussion of the strength of cast-iron lintels, illustrative examples and tables of strength.

somewhat increased by stiffening the web in the middle by brackets, as shown by the dotted lines at *A*.

Where the width of the flange must be over 16 inches two webs should be used, as shown in the section drawing, Fig. 588. For handling and molding it is better to make the flange not more than 24 inches wide; if a greater width than this is required, several

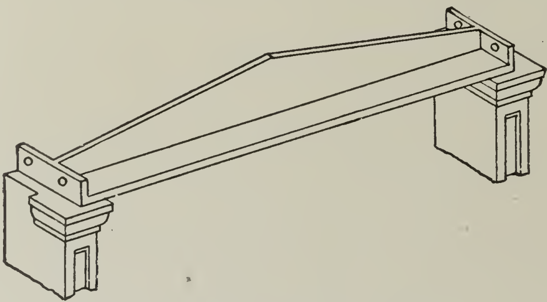


Fig. 589. Cast-iron Store Front Lintel.

lintels should be placed side by side. The thickness of the metal should be not less than ¾ of an inch, and the web should be about ⅛ of an inch thicker than the flange.

When proportioned as above the *strength of the lintel* to support a *dead* load may be safely made equal to

$$\frac{9700 \times \text{area of bottom flange} \times \text{extreme depth}}{\text{span in inches.}}$$

Thus a lintel of 6 feet clear span, with a 12-inch by ¾-inch flange and an extreme depth of 12 inches, should safely support

$$\frac{9700 \times 9 \times 12}{72} = 14{,}550 \text{ pounds.}$$

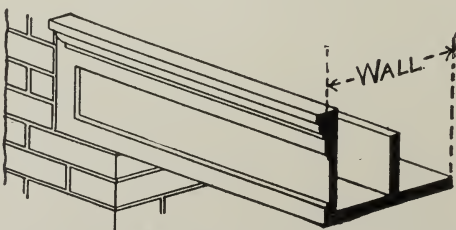


Fig. 590. Cast-iron Store Front Lintel. Front Finish.

Lintels over store fronts should be made with ribs at the ends, as shown in Fig. 589, and with holes for bolting the lintels to each other and to the columns. Store front lintels are also occasionally

made as shown in Fig. 590, in order to form a finish above the openings.

Fig. 591 shows details for a cast-iron lintel and sill, a form sometimes used for windows in exterior walls. The thickness of the metal need not exceed ⅜ of an inch.

637. CAST-IRON ARCH GIRDERS.*—These also are sometimes used to support brick and stone walls in which the openings are from 10 to 30 feet in width. Fig. 592 shows one of this kind of girders used to support a central tower over the crossing of the nave and transept in St. John's Church, Stockton, Cal., Mr. A. Page Brown, architect. The clear span is 29⅓ feet, and the height of the wall above the girder 18 feet. One object in using such a girder in this place was to get the height in the middle of the spans without at the same time raising the supports, which could not be accomplished with steel plate-girders. The church has a vaulted ceiling which comes just below the arched girder, the tie-rod being exposed.

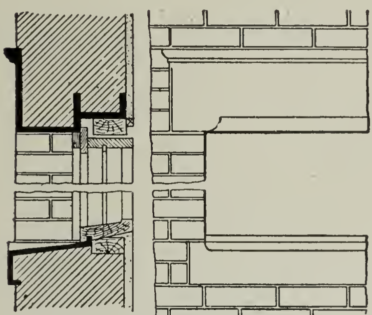


Fig. 591. Detail Section. Cast-iron Window Lintel and Sill.

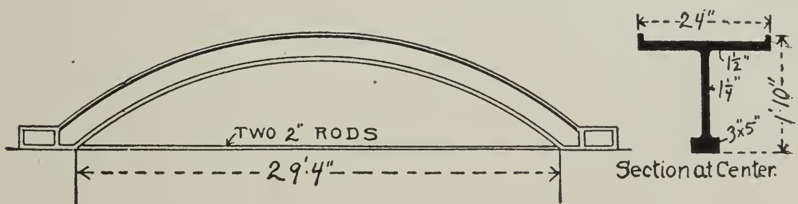


Fig. 592. Cast-iron Arch Girder.

The rise of the casting in this case is rather greater than usual, the ordinary rise being from $^1/_{10}$ to ⅛ of the span. The end of the girder is generally cast in the form of a hollow box, with shoulders to receive the ends of the rods. The tie-rods are often made with square ends, and about ⅛ inch shorter than the castings, and are heated until the expansion allows them to be slipped into their

* The reader is referred to Kidder's "Architect's and Builder's Pocket-Book." Chapter VIII, Articles "Cast-iron Arch Girders with Wrought-iron Tension Rods" and "Rules for Calculating Dimensions of Girder and Rod," for formulas, table and additional illustrations.

places in the castings. As they cool, the contraction binds each tightly into its place. If a rod is tightened by means of a screw and nut, the nut and bearings should be dressed to a smooth surface and the rod turned up with a long-handled wrench. It is very essential that the rod shall be fitted into place so tightly that no tensile stress can be developed in the casting; and it should not be expanded to such an extent that initial stresses are caused in the arch.

This form of girder is comparatively little used now, but there

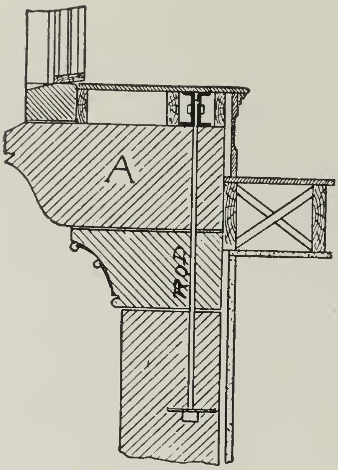


Fig. 593. Corbelled Stone Wall Support for Bay-window.

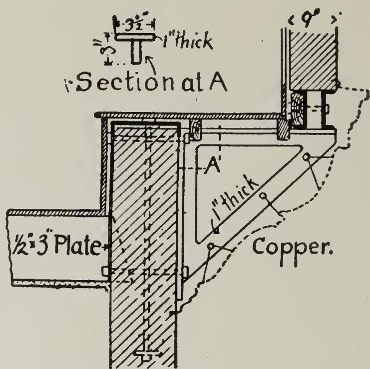


Fig. 594. Bay-window Supports. Cast-iron Brackets.

may be conditions, as there were in the church mentioned on preceding page, under which it can be used to advantage.

638. SUPPORTS FOR BAY-WINDOWS.—*Ordinary Construction.*—Where bay-windows having walls of brick, stone or terra-cotta start above the first story it is necessary to support them in some way by metalwork.

If the bottom of the bay is of stone, and the projection is not more than 2 feet, the bay may be supported directly from the wall by corbelling out the stonework, as shown in Fig. 593. The stone *A* should be the full size of the bay if possible, and should be bolted down by means of long rods built into the wall and secured to two channel-bars, as shown in the figure, placed on top of the stone and having their ends built into the main wall.

If the bottom of the bay is of copper, and at a floor level, the

simplest and strongest method of supporting the bay is the one shown in Fig. 595.

Steel I-beams are extended across the wall of the story below and framed to a pair of channels, bent to the shape of the bay. The I-beams should be carried far enough inside of the walls to give them a sufficient anchorage to offset the leverage of the other ends, and they should be secured to a girder or to a partition running parallel with the wall, or to another steel beam running at right-angles to them, and forming a part of the floor construction.

The channel-bars forming the supports for the walls of the bay should also be built into the wall on each side and anchored to it by iron rods built into the masonry below.

Fig. 594 shows a method of supporting a light bay by cast-iron

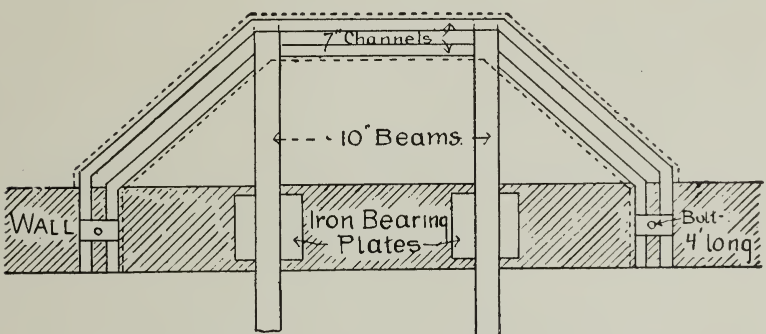


Fig. 595. Bay-window Supports. Steel Beams and Channels.

brackets bolted to the wall. This method has been used where the bottom of the bay is above the floor line. The bottom of the bay in this construction may be of either copper or terra-cotta, the latter, if used, being suspended from the brackets by hook anchors. If such a construction is used a steel channel should be bolted to the top of the wall back of the bay and extended well into the side walls, to prevent the brackets from pulling away the brickwork. Examples of bay supports in skeleton construction are shown also in Figs. 614 and 615.

639. WALL SUPPORTS IN SKELETON CONSTRUCTION.*—In buildings of the "skeleton" type, now so generally used for high office-buildings, all the weight of the walls, at least

* For a more extended discussion of curtain-walls and of masonry surrounding outer columns the reader is referred to Freitag's "Architectural Engineering" and to Birkmire's "Planning and Construction of High Office Buildings."

all above the third story, including the masonry surrounding the outer columns, is supported by the steel skeleton frame. The outer walls of the lower stories, when of stonework, are sometimes supported directly from the foundations, as was the case in the New York Life building,* Chicago, and in many other buildings erected since.

When the walls are supported by the steel skeleton they are generally made very thin, generally about 12 inches and sometimes only 9 inches in thickness; and in the more recent buildings the walls are supported at every story, so that a wall in any story can be removed without affecting the wall above or below.

The materials generally used for the outer walls are brick and terra-cotta, these being preferred on account of the ease with which they may be handled and built about and between the beams and

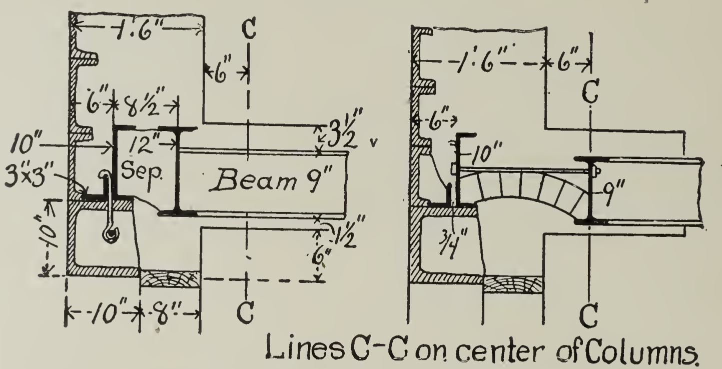


Fig. 596. Spandrel Wall Supports. Champlain Building, Chicago.

columns. Brick and terra-cotta appear also to rank as the best heat-resisting materials for the walls of fire-proof buildings.

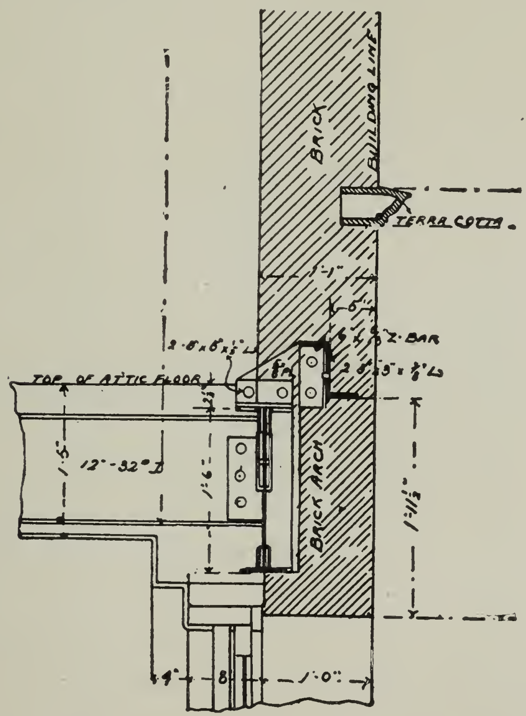
It is somewhat more difficult to attach stonework to the metal frame, and this, together with the low fire-resisting qualities of most building stones, makes the use of this material, except in the lower stories, very much less desirable. Stone has, however, been very recently used for the entire outside casing of some very high and very important buildings.

The general plan of the exterior walls in this class of buildings consists of vertical piers, from 3 to 4 feet wide, which inclose the exterior columns and extend from the bottom to the top of the

*Jenney & Mundie, architects.

building. The space between these piers is generally nearly filled by the windows, either flat or in the form of bays, leaving only a small piece of wall, from 4 to 5 feet high, between the tops and bottoms of the windows, to be supported by the steel frame. These portions of walls between the piers and the windows are called "spandrels."

The masonwork of the piers is generally supported by angle brackets attached to the columns, and the spandrels are supported by steel beams or girders of various shapes, and called "spandrel



SECTION THROUGH ATTIC

Fig. 597. Spandrel Wall Supports. Wyandotte Building, Columbus, Ohio.

beams." The spandrel beams extend from column to column, and are rivetted to them.

The arrangement of the metalwork for supporting the spandrel walls will depend largely upon the architectural effect sought by the designer and upon the materials used; so that the details vary somewhat in every building, and often in different portions of the same building. No general rule or form of construction can there-

fore be given for arranging such supports, and the architect must use such arrangements as seem best suited to the design of the building he has in hand. The following examples, however, will show how the walls have been supported in several buildings, and with slight variations one or another of these methods can be adapted to almost any building.

It is probably hardly necessary to say that the metalwork in this class of buildings should be very carefully designed and studied to suit the conditions of the building and to provide ample strength; and it should also be so arranged that it may be fully protected from

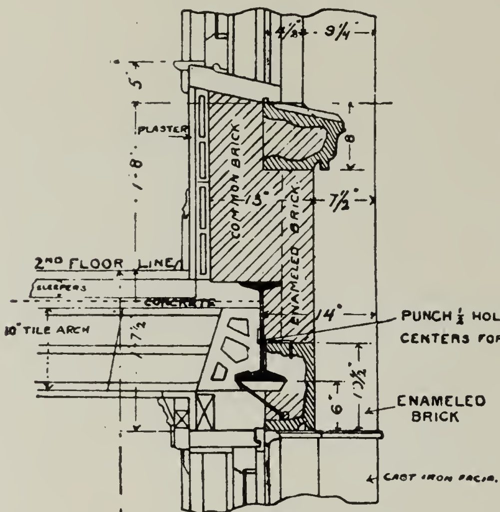


Fig. 598. Spandrel Wall Supports. New York Life Building, Chicago.

heat. Consideration is also sometimes given to the effects of expansion and contraction in the frame.

640. SPANDREL SUPPORTS.—The simplest case of spandrel supports is the one in which the walls are perfectly plain and built of brick, with terra-cotta caps and sills. In such cases a channel and an angle-bar may be used to support the outer face of the wall, and an I-beam to support the backing, as indicated in Fig. 596, which shows sections of the outer walls of the Champlain building, Chicago.*

The channel and I-beam should be bolted together with cast-iron separators made to fit.

* Holabird & Roche, architects.

For plain walls, channels and angles seem to be the best shapes for the outer portion of a spandrel support, as they are economical sections, and the flat face of the channel being turned outward, a 4-inch veneer of brickwork can be set in front of it without clipping the bricks. The face of the channel is generally set 5 or 6 inches back from the face of the wall, and 3-inch by 3-inch angles are used for the purpose of supporting the outer 4 inches of the wall. The outer edge of the angle should come within 2¼ inches of the face of the wall.

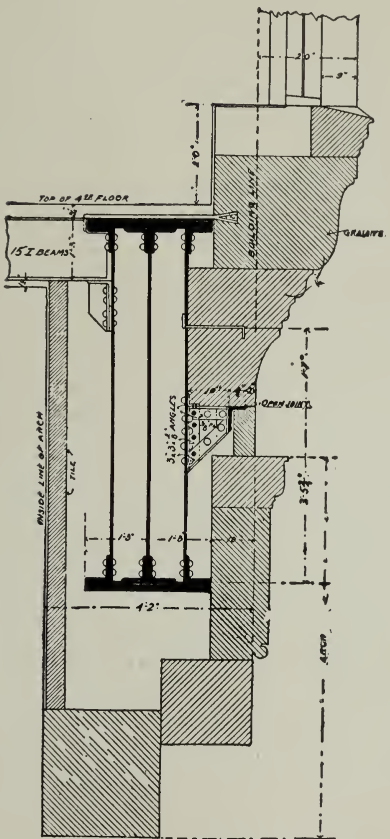


Fig. 599. Spandrel Wall Supports. Masonic Temple, Chicago.

Spandrel supports very similar to those shown in Fig. 596 have been used in several Chicago buildings.

Z-bars also were used in several buildings in place of the channels and angles, but were generally considered not quite as satisfactory, as they do not give the same strength for the weight of metal used. They are no longer used.

Fig. 597 shows a Z-bar support used for the attic wall of the Wyandotte building, Columbus, Ohio.*

Fig. 598, from the New York Life Insurance Company's building, Chicago, shows the spandrel supported by a single I-beam, the 4-inch facing of the wall being supported by the terra-cotta lintel which is hung from the beam.

In the Reliance building,† plate-girders were used for the main spandrel supports, and two angles rivetted together to make a T

* D. H. Burnham & Co., architects.
† D. H. Burnham & Co., architects.

were bracketed from the outer face of the girder to support the wall, the girder being on the center line of the columns.

Fig. 599 shows the method used for supporting the granite walls at the fourth floor level of the Masonic Temple, Chicago. It should be noticed that an open joint is left opposite the supporting angle to allow for expansion and contraction in the steel columns.

When the wall is faced with ornamental terra-cotta, the latter can seldom be supported directly by the spandrel beams, and a system of anchors must be resorted to to properly tie the individual blocks either to the brick backing or to the metalwork. These anchors are

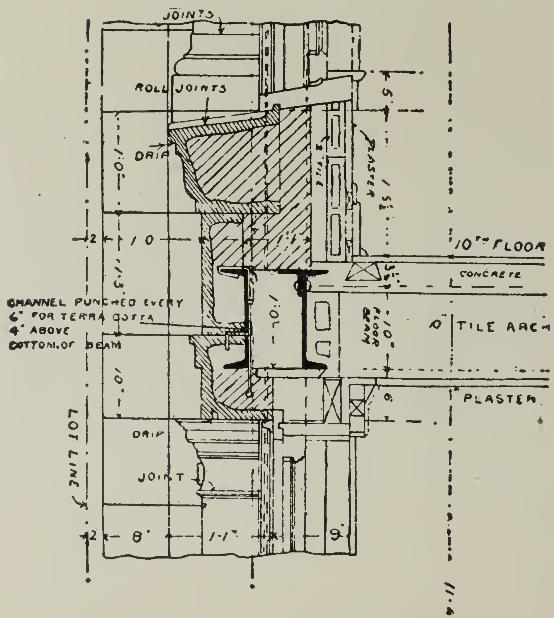


Fig. 600. Spandrel Wall Supports. New York Life Building, Chicago.

usually made of ¼-inch square or round iron rods, which are hooked into the ribs provided in the terra-cotta blocks, and then drawn tight to the brickwork or metalwork by means of nuts and screw ends, as shown in Fig. 614.

Hook-bolts are largely used for tying terra-cotta blocks to the metalwork, the ends being bent around the bottom of the beams, channels or angles. Several examples of the use of hook-bolts are shown in Figs. 598 to 615.

A great variety of methods for properly securing the terra-cotta

are possible. They should be carefully studied and the general scheme should always be indicated on the spandrel sections, in the manner shown in the illustrations, as the holes in the structural

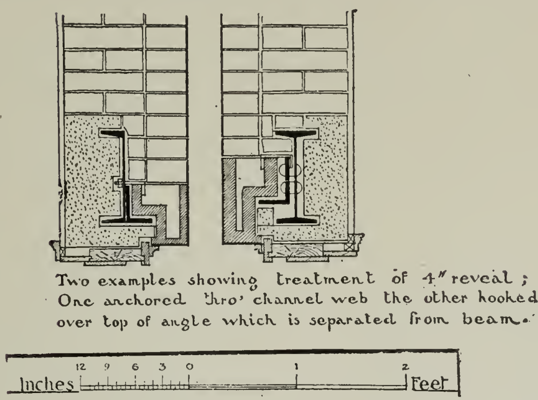


Fig. 601. Steel Supports for Masonry. Terra-cotta Lintel Construction.

metalwork necessary to receive the anchors should be shown on the detail drawings of the iron and steel work, so that the punching may be done at the shop. The inexperienced architect should also consult with the manufacturers of the terra-cotta work as to the best manner of securing the blocks.

The anchorage of the brick and terra-cotta to the steel frame is a

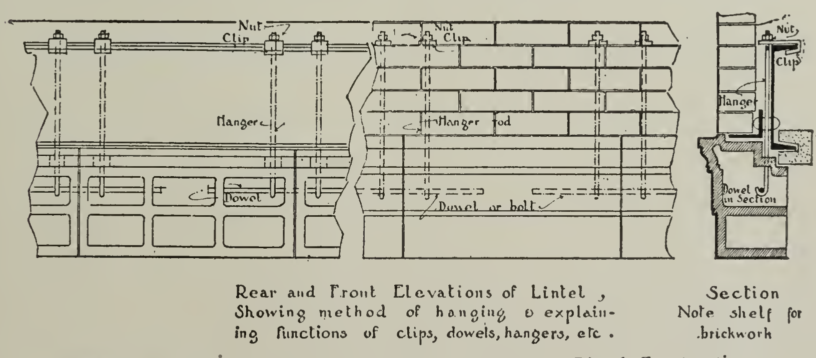


Fig. 602. Steel Supports for Masonry. Terra-cotta Lintel Construction.

matter of vital importance, as very serious consequences are quite sure to follow any neglect in this matter. "An instance is known where a whole section of wall facing on the court side of a high

building fell off because the workmen omitted the anchors." As all the anchors for every block cannot be exactly shown on the drawings, either the architect or some one in his employ should give this portion of the work the strictest superintendence.

641. STEEL LINTEL SUPPORTS FOR MASONRY.*—Figs. 601 to 612, both inclusive, illustrate various forms of metal supports for curtain walls and terra-cotta lintels.

Fig. 601 shows two examples indicating the treatment of 4-inch reveals. One shows an anchor through the channel web and the

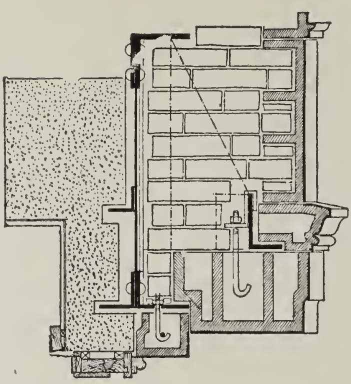


Fig. 603. Steel Supports for Masonry. Shelf Bearing and Rod Suspension.

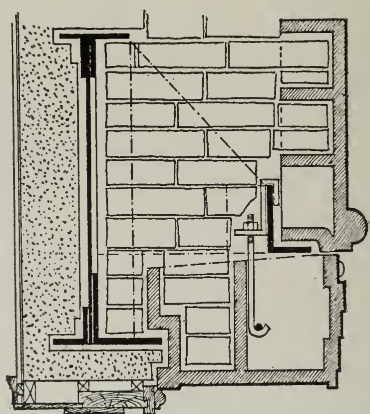


Fig. 604. Steel Supports for Masonry. Terra-cotta Lintel Construction.

other a tie or anchor hooked over the top of the steel angle which is separated from the I-beam.

Fig. 602 shows section and front and rear elevations of metal supports for terra-cotta lintels and masonry above. The section shows the angle shelf for supporting the 4-inch brick facing, and the two elevations show the method of hanging and the functions of the clips, dowels, hangers, etc.

Fig. 603 shows curtain-wall supports with angles, brackets, hook-bolts, etc., for holding up double terra-cotta lintel and masonry above.

* These illustrations are reproduced through the courtesy of the Northwestern Terra-cotta Company, of Chicago, Ill.

Fig. 604 shows the steel supports, and a single terra-cotta lintel resting on angle shelf and also hung on hook-bolt, and the wall facing above resting on angle shelf fastened to steel bracket from the plate-girder.

Fig. 605 shows metal supports formed by I-beam, angle and anchor. The terra-cotta lintel has a shelf bearing with anchor clamped over top flange of beam. The staff-bead is so placed that the terra-cotta lintel will not be injured from any deflection of the I-beam.

Fig. 606 shows metal supports formed by I-beam, channel, three

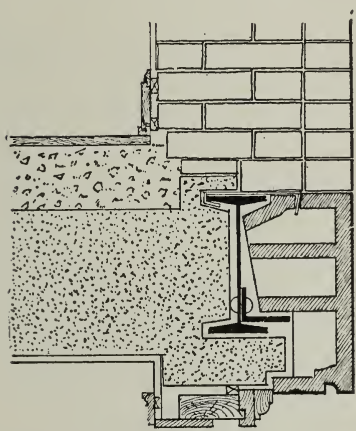


Fig. 605. Steel Supports for Masonry. I-beam, Angle and Anchor.

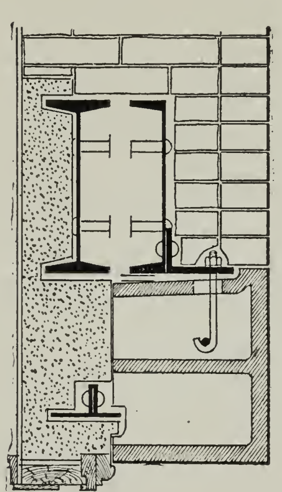


Fig. 606. Steel Supports for Masonry. I-beam, Channel, Three Angles and Hook-bolt.

angles and a hook-bolt. The terra-cotta lintel is suspended from the angle shelf, and this same shelf, formed by the long horizontal leg of the angle, supports the 8- or 9-inch brick facing of the wall above.

Fig. 607 shows metal supports formed by I-beam, channel, angle and hook-bolt. In this example there is a double terra-cotta lintel, the outer one being supported by the long angle shelf rivetted to the channel web and anchored to top flange of channel, the inner or lower one being hung by a hook-bolt from a plate resting on lower flanges of the I-beam and the channel.

Fig. 608 shows metal supports formed by plate-girder, channel, two angles, anchor and hook-bolt. The outside lower lintel of terra-cotta is supported by an angle shelf rivetted to lower part of channel web, and is also tied or anchored back by anchor running through channel web. This shelf and its supported terra-cotta lintel also supports the terra-cotta wall facing above. The terra-cotta soffit is supported by a hook-bolt run through a steel plate resting on lower flanges of channel and plate-girder.

Fig. 609 shows metal supports formed by two channels, two

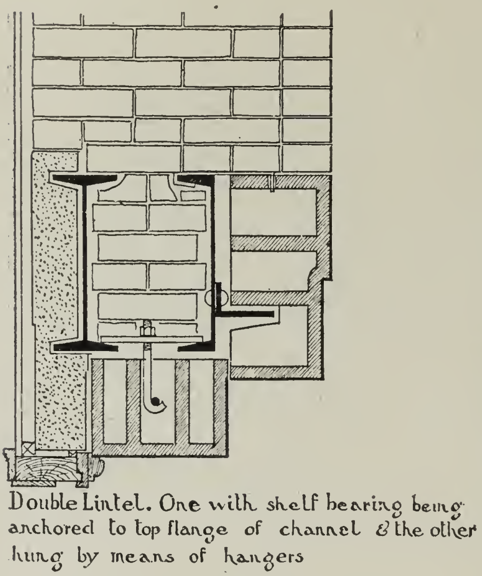


Fig. 607. Steel Supports for Masonry. I-beam Channel, Angle, Plate and Hook-bolt.

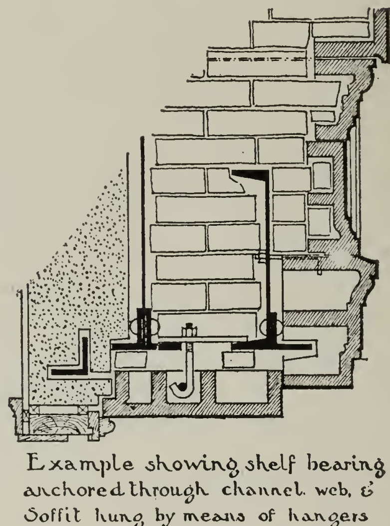


Fig. 608. Steel Supports for Masonry. Plate-girder, Channel, Two Angles, Anchor and Hook-bolt.

angles, anchor and hook-bolts. The terra-cotta face lintel is bedded on the angle shelf rivetted to channel web and also anchored back by anchor caught around top flange of channel. The soffit is suspended by hook-bolts through a steel plate resting on the lower flanges of channels.

Fig. 610 shows metal supports formed by I-beam, channel, angle and hook-bolt. The terra-cotta outside face lintel rests on an angle shelf and is also tied back by anchor running over top of channel flange. The soffit is suspended by an outside hook-bolt and also has its inside edge supported on the lower flange of the I-beam.

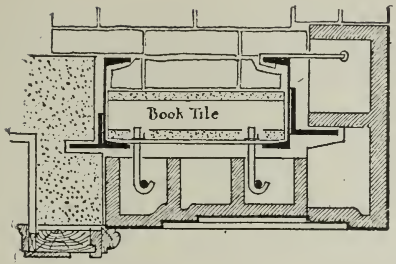


Fig. 609. Steel Supports for Masonry. Two Channels, Two Angles, Anchor and Hook-bolts.

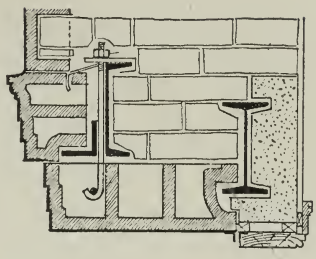


Fig. 610. Steel Supports for Masonry. I-beam, Channel, Angle, Anchor and Hook-bolt.

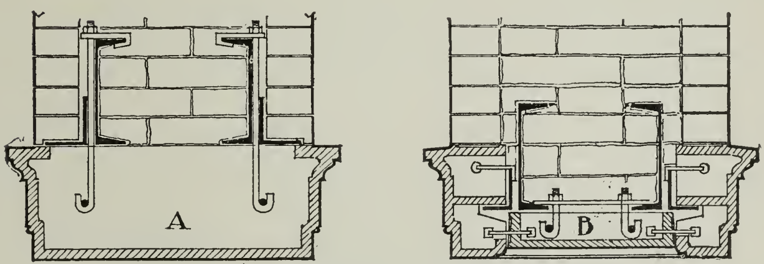


Fig. 611. Steel Supports for Masonry. Incorrect and Correct Methods.

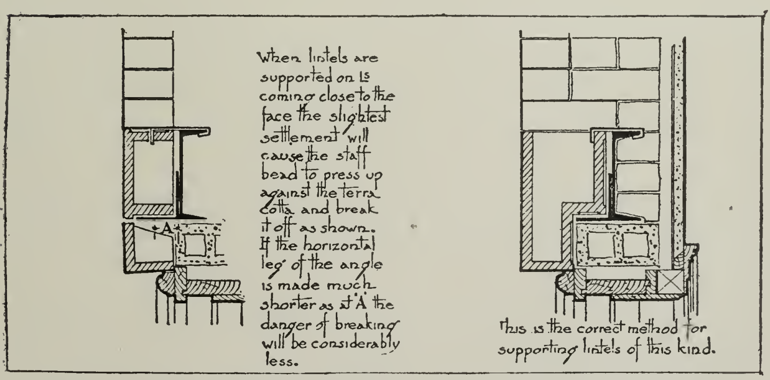


Fig. 612. Steel Supports for Masonry. Incorrect and Correct Methods.

Fig. 611 shows metal supports formed by channels, angles, anchors, hook-bolts and plates as indicated. The figure on the left shows the incorrect method of constructing a wide terra-cotta soffit, that is, in making it in one piece. The figure on the right shows the correct method, the one in which the wide soffit is cut up into more than one piece, three pieces in this case, in order to insure a perfect alignment when the pieces shrink unequally. The method of support is clearly shown in the drawing.

Fig. 612 shows incorrect and correct methods of supporting terra-cotta lintels by metal supports in cases in which there is a tendency to break off a portion of the terra-cotta lintel by some settlement of the metal supports. The drawing on the left shows the incorrect method of construction in which the lintel is supported on an angle which comes close to its face. The slightest settlement will cause the staff-bead to press up against the terra-cotta and break it off as shown. In the drawing on the right the angle is shown with horizontal leg made much shorter, as shown by the distance "A," the danger of breaking the terra-cotta being thus considerably less.*

642. STEEL SUPPORTS FOR CORNICES.—In any discussion of the iron and steel supports for masonwork the subject of the metal supports for cornices of stone or terra-cotta should be referred to with at least one general type of support given in illustration. Terra-cotta and stone cornices vary so much in profile, height and projection that many variations could be shown in the way of metal supports. In this connection the reader is referred to the many illustrations of terra-cotta cornice construction given in Chapter VIII, on "Architectural Terra-cotta," as these illustrations include the steel supports.

One additional illustration of steel supports for terra-cotta cornice work is given here, and reproduced through the courtesy of *The Brickbuilder,* which contains in its various issues many excellent examples.

Fig. 613 shows the metal support for the terra-cotta cornice of the Chamber of Commerce building, in Rochester, N. Y., Nolan, Nolan & Stern, architects.†

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* See also the numerous illustrations of steel and iron supports for masonry in Chapter VIII, "Architectural Terra-cotta," shown in connection with terra-cotta construction.

† For full descriptions of many architectural terra-cotta constructions and their metal supports, see series of articles in *The Brickbuilder* for 1897-98, and in still more recent issues, by Mr. Thomas Cusack, from whose descriptions the above is taken.

This cornice is 8 feet 9 inches high, and, having a total projection of 5 feet from wall line to nose of lion's head, requires a well-devised scheme of structural support. The one that was adopted is shown in detail in Fig. 613. To the Z-bar columns that extend up through the piers is bracketed, horizontally, a 10-inch I-beam. This acts as a fulcrum for a series of 6-inch I-beams that project over each modillion, the opposite ends being attached to roof beams by means

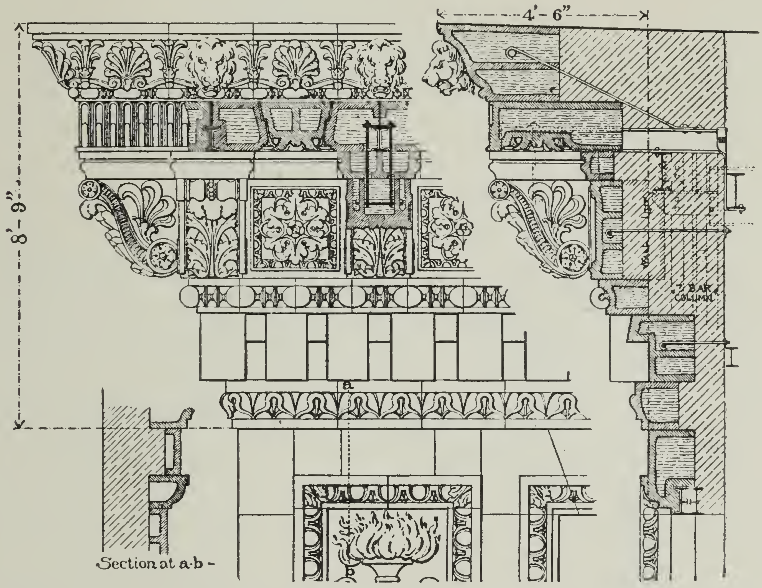

Fig. 613. Steel Supports for Terra-cotta Cornice. Chamber of Commerce Building, Rochester, N. Y.

of stirrups. These cantilevers, in addition to the weight that rests on top of them, are strong enough to support the modillions also. This they are made to do by the application of two ¾-inch hangers, which, taking hold of a short bar inserted in each modillion, pass up through a plate laid across each cantilever, where they are tightened up to the required tension. The dentil course and the panels between modillions have each a series of holes through which rods are passed, and around which anchors hook and run back through the wall.

The modillions are spaced 3 feet 8 inches on centers. This made it inadvisable to design the soffit blocks in single pieces. They are therefore divided into three pieces for greater convenience in hand-

ling and setting, as well as in making. This allows the two side pieces to be fitted into the flanges and bedded down to each side of the cantilever. The middle piece, to which the coffer panel is attached, is then dropped in as a key, and the whole course is thus made immovable. A hole is provided in the blocks forming the cymatium, into which short pieces of round iron are inserted, and

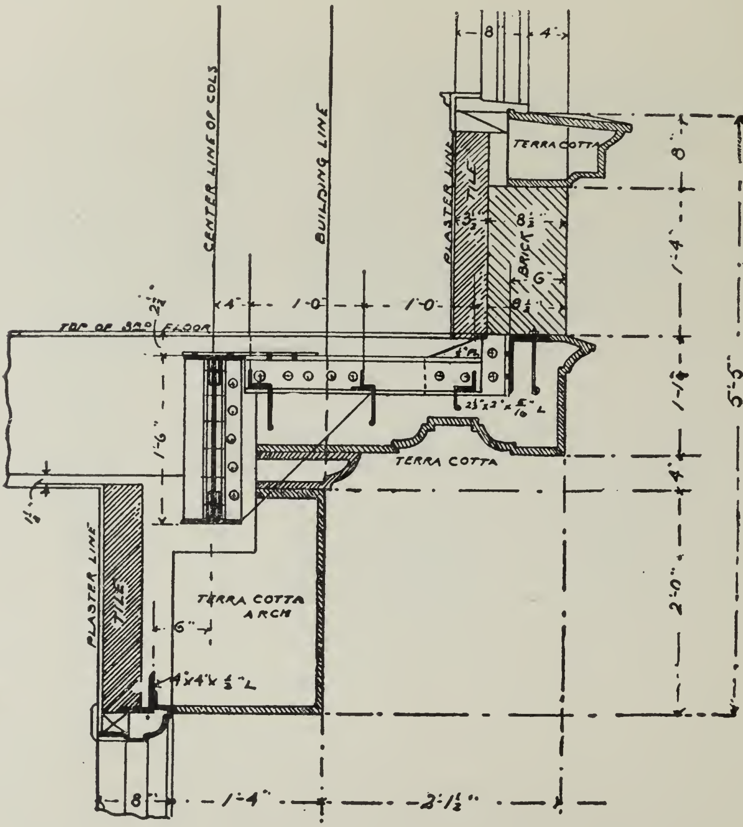

Fig. 614. Bay-window Supports. Wyandotte Building, Columbus, Ohio.

from these diagonal braces are run at intervals and rivetted to the 6-inch I-beams, as indicated in the section. The top surface of this cornice is covered with copper.

643. BAY-WINDOWS IN SKELETON CONSTRUCTION.—(See also Article 638.) These have become very prominent features in the modern office-buildings and hotels. In skeleton buildings the masonwork of the bays is made as light as possible, with slender

terra-cotta mullions and angles, and is supported in each story by brackets built out from the spandrel beams or girders, as shown in Figs. 614 and 615, which are sections from the Wyandotte building, Columbus, Ohio.

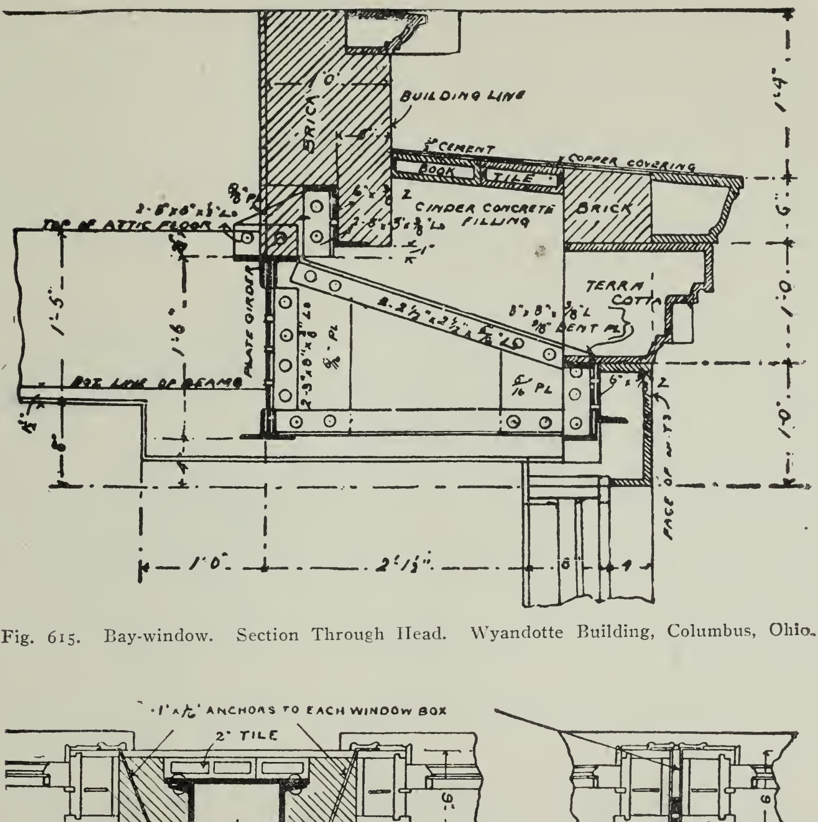

Fig. 615. Bay-window. Section Through Head. Wyandotte Building, Columbus, Ohio.

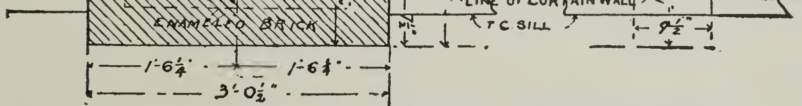

Fig. 616. Plan of Piers and Mullions in Alley and Light-court, New York Life Building, Chicago.

As the leverage on these brackets is considerable, they should be securely rivetted to the spandrel beams, and the latter well tied or framed to the floor construction to keep them from twisting.

Where mullions occur between windows, and at the angles of the bays, cast-iron or steel angles or T-bars are bolted or rivetted to the metalwork above and below, to stay the frames and terra-cotta mullions and angles, in the manner shown in Fig. 616.

644. WALL COLUMNS.—The importance of thoroughly fire-proofing the exterior columns has already been considered in Chapter IX. Fig. 616, however, is given as one example of pier construction in some Chicago buildings.

Further illustrations of the manner of supporting the masonwork in this class of buildings may be found in "Architectural Engineering," by Joseph K. Freitag, C. E., and in many numbers of *The Engineering Record* and of *The Brickbuilder*.

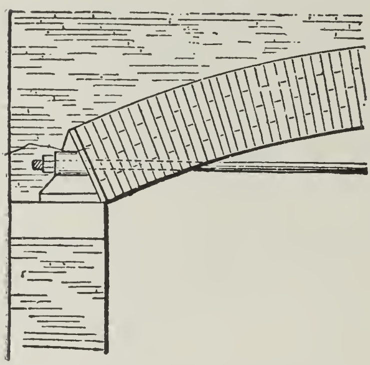

Fig. 617. Cast-iron Skewback for Brick Arch.

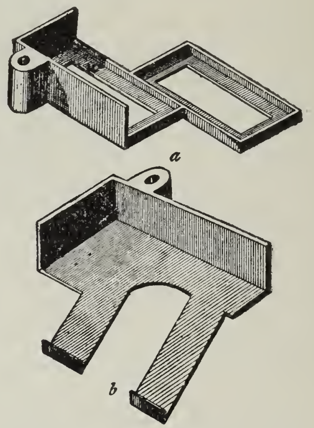

Fig. 618. Cast-iron Shutter-eyes. *a*. Form for Brick Walls. *b*. Form for Stone Walls.

645. MISCELLANEOUS IRONWORK.—The following details of ironwork used in connection with brickwork and stonework should perhaps be mentioned here, as they have to be considered when designing the masonwork.

Bearing-plates.—Wherever iron or wooden posts, columns or girders rest on brickwork, a cast-iron or stone bearing-plate should be used to distribute the concentrated weight over a safe area of the masonwork. Several failures in buildings have resulted from carelessness in this particular. Rules for proportioning the size of bearing-plates are given in the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

Cast-iron Skewbacks for Brick Arches.—Whatever segmental

arches are used over doors or windows, without ample abutments, cast-iron skewbacks, connected by iron rods of proper size, should be used to take up the thrust of the arch, as shown in Fig. 617.

Shutter-eyes.—All fire-proof doors and shutters in brick or stone walls should have hinges made of 2-inch by ¾-inch flat iron bars, welded around a ¾-inch diameter pin working in a cast-iron shutter-eye built into the wall. For brick walls the shape shown at *a*, Fig. 618, is about the best for the eyes, although for very heavy doors or shutters the strength of the face should be increased by the addition of another web. For stone walls the shape shown at *b* should be used. The thickness of the metal is generally made ¼ of an inch.

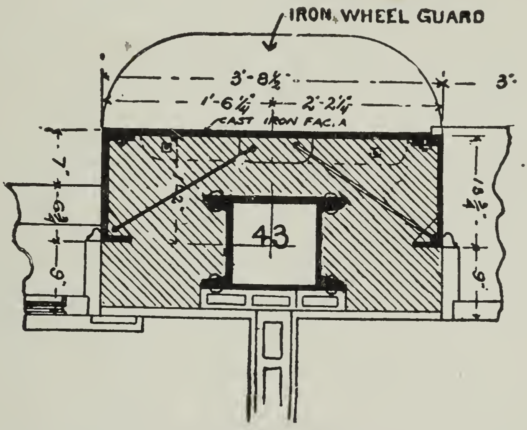

Fig. 619. Iron Wheel-guard. Alley Pier, New York Life Building, Chicago.

Door-guards and Bumpers.—It is a good idea to protect the brick jambs of the carriage doors in stables by bumpers, which are rounded projections on the corners, extending a distance of from 12 to 18 inches above the ground and to a point about 8 inches beyond or in front of the wall and the jambs, so that if a carriage wheel strikes the bumper the hub will not scratch the brick jambs. Such bumpers may be made either of some hard stone or of iron. The jambs of the outside doorways to freight elevators also, and of the delivery and receiving doorways in mercantile buildings, should be protected to a height of 4 or 5 feet above the sills by iron guards, to prevent the brickwork being broken by boxes, trucks, etc. Such guards are generally made of cast-iron about

½ of an inch thick, as it is easier to fasten castings to a wall than it is to fasten plate-iron. The castings, or plates, should be made with lugs on the inside pierced with holes for clamping them securely to the brickwork as the wall is built. Fig. 619 shows a section of one of the alley piers of the New York Life building, Chicago, and the manner in which the iron guards are attached to the brickwork. A similar arrangement can be adapted to any door jamb. It is quite common to protect the bottoms of the piers on the alleys in this way to prevent injury to the walls from passing teams.

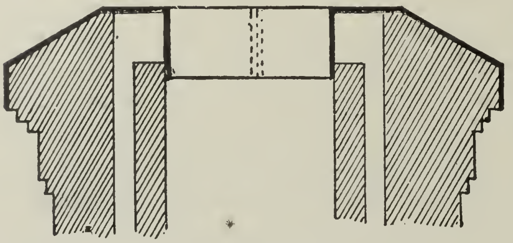

Fig. 620. Cast-iron Chimney Cap. Common Form.

Chimney Caps.—For many kinds of tall brick chimneys cast-iron caps are generally considered durable finishes for the top. A common form for such caps is that shown in Fig. 620. Such a cap completely protects the mortar joints from the weather and prevents the bricks in the upper courses from becoming loose. If the chimney is corbelled out as shown the cap acts also as a drip to protect its sides, or at least their upper parts. The inner lip of the cap should extend down into the chimney a distance of from 8 to 12 inches. If the cap is not more than 4 feet square it need not be thicker than ¼ of an inch; but if it is larger than this the thickness should be increased to ⅜ of an inch.

If the cap is 3 feet or more square, for convenience in handling it should be cast in two or four sections, which should be bolted together, flanges being cast on the under side for this purpose.

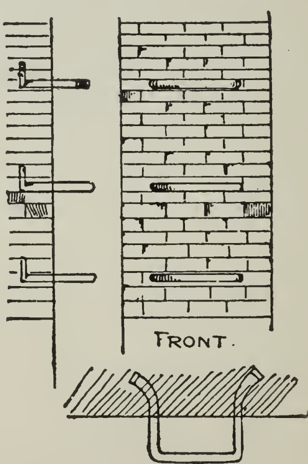

Fig. 621. Chimney Ladder.

Chimney Ladders.—It is sometimes desirable to have ladders built on the inside of large brick flues or shafts and on the outside of tall chimneys, to serve as ready means of reaching the top.

Such ladders are usually made of ¾-inch round iron bars, bent to the shape shown in Fig. 621, and placed in the wall of a chimney, or flue, as it is built. For easy climbing the rungs should be placed 12 inches on centers, and they should be about 18 inches wide, with a projection of about 6 inches out from the wall.

Coal-hole Covers and Frames.—When coal vaults are placed under a sidewalk the architect should specify iron frames and covers for the holes made for putting in the coal. If a vault is covered with granite flagging a rebate may be cut in the stone to receive the cover, in which case no frame is necessary. In stones of all other kinds, and in cement walks, the holes should be protected by a cast-iron frame at least 4 inches deep. A frame of this kind is generally cast with a projecting ring about 2 inches wide and ½ of an inch thick, which should be set in a rebate cut in the stone and filled with soft Portland cement. It is made also with a ¾-inch rebate for the iron cover, which is made of cast-iron about ½ of an inch thick and with a roughened top surface. These covers are sometimes made with holes, into which glass bull's-eyes are cemented in order to admit light to the vault. Both solid and glazed covers are generally carried in stock by the larger iron foundries, and in sizes varying from 16 to 24 inches in diameter.

Chapter XII.

Lathing and Plastering.

646. GENERAL CONSIDERATIONS.—Probably 99 per cent of modern buildings, in this country, at least, have plastered walls, ceilings and partitions. It is only lately, however, that much attention has been given to this branch of building operations, and it is doubtless true that much of the plastering done at the present day is inferior to that done fifty or one hundred years ago.

The introduction of fire-proof construction and the desirability of completing large and costly commercial buildings in the shortest possible time have shown the necessity for improvements in the materials used both for lathing and plastering, and several new materials have been introduced to meet these demands.

Even in dwellings it is important to have the finish of walls and ceilings as nearly perfect as possible, as large sums of money are not infrequently spent on their decoration; and it is therefore essential that the groundwork shall be so durable that the decorations will not be ruined by broken walls or falling ceilings. The quality of the workmanship is also of much importance, as nothing mars the appearance of a room more than crooked walls and angles, and dents, cracks and patches in the plastering.

To secure a good job of lathing and plastering it is essential that only the best materials be specified and used, and that the mortar be properly prepared and applied. Good results are obtained only by carefully specifying exactly how the work is to be done and what materials are to be used, and by supplementing these specifications by efficient supervision. In order to furnish such specifications and superintendence it is obviously necessary that the architect shall be thoroughly familiar with the materials used and with the way in which they should be applied.

Brick, tile and concrete walls, ceilings and partitions do not require lathing, as the plastering may be applied to them directly, these materials having an affinity for the mortar which is held

securely in place. Other constructions require some form of lathing to serve as a ground to receive and hold the plaster.

647. WOODEN LATHS.—Practically all dwellings of moderate cost, and a large proportion of other buildings, are still lathed with wooden laths; and if of good quality they give very satisfactory results where no fire-proof properties are expected. It is generally admitted that the best wood for laths is white pine, although nearly as many are made of spruce, which answers very well. Hard pine is not a good material for laths, as it contains too much pitch.

Wooden laths should be well seasoned and free from sap, bark and dead knots. Small sound knots are not particularly objectionable. Bark is often found on the edges of laths, and is probably the greatest defect found in them, as it is quite sure to stain through the plaster.

The usual dimensions of wooden laths are ¼ by 1½ inches in cross-section and 4 feet in length; the width and thickness vary somewhat in different mills, but the length is always the same. The studding or furring strips should therefore be spaced either 12 or 16 inches apart on centers; 12-inch spacing gives five nailings and 16-inch spacing four nailings to a lath.

The former obviously makes the stronger and better wall. It is particularly desirable that laths on ceilings have five nailings, as there is a greater pull on them than on those on the walls.

648. SHEATHING LATH.—Combination sheathing and lath, such as the Byrkit-Hall sheathing lath, has been on the market for many years. It is made by special machinery from pine, hemlock, cypress and poplar, in the same lengths as flooring and in 4-, 6- and 8-inch widths, the edges being either tongued and grooved or square. The general form of the lath is shown in Fig. 622.

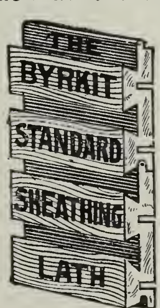

Fig. 622. Byrkit-Hall Sheathing Lath.

When used on the outside of frame walls it answers the purpose of sheathing, and also forms a clinch for back-plastering on the inside.

For stuccowork, staff, plaster-of-Paris ornamentations and imitations of stone, it can be placed with the grooved side out, to receive the mortar.

Thirty million feet of this lath were used on the Columbian Expo-

sition buildings in 1892 and 1893; twelve million feet on the Pan-American Exposition buildings and about thirty million feet on the Exposition buildings at St. Louis, Mo. In the North, Northwest and Middle States this lath has been extensively used for rough-cast work, back-plastering and interior lathing.

649. METAL LATH.—The different kinds of metal lath are classified in Article 479 and described in detail with illustrations in the succeeding articles in Chapter IX.

At about the same time that the interest in fire-proof construction became more general, wire netting came into use as a substitute for wooden laths. It was found that the strands of the netting became completely imbedded in the plaster and held it so securely that it could not become detached by any ordinary accidents. It was found also that the plaster protects the wire from heat, and that the body of the metal is so small that it has no appreciable expansion when subjected to fire.

Plasters on metal lath, and particularly hard plasters, will protect woodwork from a severe fire as long as the plasters remain intact, provided there are no cracks or loopholes at the corners and around columns where the fire can get through.

Objection has been made to the ordinary wire lath that it is difficult to stretch it so tight that it will not yield to the pressure exerted in applying several coats of mortar. Another objection, and one that is made to the use of expanded-metal lath also, is that they both take a great deal of plaster. From the standpoint of *first cost* this is undoubtedly a valid objection; but from the standpoint of fire-resistance the great amount of mortar used is its greatest recommendation. It should be remembered that the *mortar*, and *not* the metal, is the *fire-resisting* part of a wall or ceiling. No metal lath, the author believes, should be considered fire-proof which does not, in use, *become imbedded in the mortar;* for if the thin coating of plaster peels off many kinds of metal lath will resist the fire no better than will the wooden laths and will be more in the way of the fireman.

Wire lathing is now made in great variety to meet the requirements of the different plaster compositions and the varying conditions of construction.

In order to properly protect wooden construction, such as beams, posts, studding or planks, from fire by means of wire lath and

plaster, it is essential that the lath be kept at least ⅜ of an inch away from the woodwork by iron furring of some form. A 1-inch space is still better. This setting off of the lath from the wood is generally done either by means of bars woven into or attached to the lathing, or by means of iron furring put up in advance of the lathing. The various methods of furring are described in Articles 480 to 483, in connection with the description of the different metal laths themselves; and metal wall furring and furring for architectural forms are described in Articles 486 and 487.

When using common lime mortar on metal lath the first coat should be gauged with plaster of Paris. Painted, galvanized or japanned lath should always be used for hard plasters which are made by chemical processes.

Aside from their fire-resisting qualities, wire laths or metal laths possess these advantages: plastering applied to them does not crack from the shrinkage of woodwork and the plaster does not fall off. If the lathing is set away from the wood studding the location of the timbers is not shown by the plaster, as is often the case after a few years when wooden laths are used. Metal laths are also proof against rats and mice, a property which makes them especially desirable in certain kinds of store buildings. Many of these advantages are lost, however, when unstiffened wire cloth is stretched over wood furrings.

650. WALL-BOARDS AND PLASTER-BOARDS. — Thin boards made of plaster and reeds of fiber have been quite extensively used, not exactly as laths, but as a ground for the second and third coats of plaster. They are made in slabs of varying lengths, widths and thicknesses.

For a general description of wall-boards and plaster-boards see Article 470, included in the description of plaster-block and wall-board partitions.

The boards can be sawed into any size or shape and nailed directly to the under side of the joists or to studding or furring. They are rapidly put on and require no scratch coat, and with some styles of boards a white or finished coat is all that is necessary.

On account of their lightness, and the ease with which they can be cut, they are sometimes preferred to tile or terra-cotta for suspended ceilings under iron beams.

Owing to the saving of plaster, the low cost of the boards and

the ease with which they are put up, plaster-boards have been used to a considerable extent in some parts of the country.

In using plaster-boards, or any of the patented laths, the architect or builder should follow the directions of the manufacturers as to the manner of putting in place, etc., as there are often important precautions which might otherwise be overlooked.

651. WHERE METAL LATH SHOULD BE USED.—It is of course desirable that metal lath or plaster-boards should be used wherever any lathing is required, but the increased expense generally prevents their use in the majority of buildings.

There are, however, many places where metal lath is particularly desirable, especially in buildings having ordinary wood floors and partitions. Such places are the under side of stairs in public buildings, the ceilings in audience and assembly-rooms, the under side of galleries, the ceilings of boiler-rooms, furnace-rooms. etc.

Metal lath should be used also on both sides of hot-air pipes in wood partitions. Where there are slots in brick walls for plumbing pipes, hot-air pipes or steam pipes, they should be covered with metal lath, unless the walls are furred or the recesses cased with boards.

Metal lath should be used also at the joining of wood partitions and brick walls when the walls are not furred; and particularly when the partition is parallel and flush with the wall.

By using a strip of wire lath or expanded-metal, lapped 12 inches on the wall and partition, a crack at the juncture of the two will be avoided, and at only a very slight additional expense.

It very often happens in outside brick walls that the arched wooden lintels over the windows come partly above the casing, and if the wall is plastered directly on the brickwork the plastering generally cracks over the lintel, or does not stick to it. This can be avoided by covering the lintel with a strip of metal lath, lapped 6 or more inches on the brickwork.

In general, wherever solid timber has to be plastered, and where there is no room for furring and lathing, it should be covered with metal lath, which should also be lapped well on the adjoining partition or wall.

652. INTERIOR PLASTERING.—The very general practice of plastering walls and ceilings dates back not much more than a century. Previous to that time the walls and ceilings were wain-

scoted, boarded covered with canvas or tapestries or else left rough.

On account of its cheapness, its fire-resisting and deafening qualities, and its adaptability to decorative treatment, some kind of plastering will probably always be used for finishing the interior walls and ceilings of buildings.

In describing plastering operations it will be more convenient to consider the subject under the headings: "Lime Plaster," "Hard or Cement Plaster," "Interior Stuccowork" and "Exterior Plastering."

653. LIME PLASTER.—Up to about the year 1885 all interior plastering used in this country was made of quicklime, sand and hair.

There can be no question but that plaster made of a good quality of lime, thoroughly slaked and mixed in the proper manner, is very durable and also a valuable sanitary agent. Most of the lime plaster used at the present day, however, is very poorly and cheaply made, often of poor materials, and very much of it far from durable.

The stones from which lime is made, the characteristics of good lime, the methods of slaking and making into mortar, hydrated lime, the sand used in lime mortar, the setting and durability of lime mortar, etc., are fully discussed in Articles 145 to 153.

While the mortar considered in these articles is for laying up masonry, the statements made relate also generally, with some few exceptions, to mortar for plastering.

There are some limes which, while good enough for making ordinary mortar for masonry, are not suitable for making plaster; this is because all the particles of the lime do not immediately slake. Some of the particles, because they are overburned or for some other reason, do not slake with the bulk of the lime, but continue to absorb moisture; and finally, after a long period, extending sometimes over two years, they slake or "pop" and cause bits of plaster to fall off.

The author has seen walls and ceilings that were pitted all over from this cause.

It is therefore important that the architect, when building in a new locality, or upon commencing his practice, should make inquiries as to the slaking qualities of the lime at hand; and, where more than one lime is available, as to which one is the best. In some localities four or five different qualities of lime, from as many

different places, are found on the market; and in such cases the architect should be very careful to specify that particular lime which he considers the best. Limes are generally known by the name of the locality in which the rocks are quarried. Even in the best limes some particles do not slake quite as quickly as others, and it is not generally safe to apply any plastering in which the lime has not been slaked from ten days to two weeks.

The usual specifications for sand used in making mortar for plastering require that it shall be angular, not too coarse nor too fine and free from dust and all foreign substances. Methods of testing sand for foreign substances and conclusions reached from recent tests and experiments are discussed in Article 149.

For the very best plaster the sand should be *screened, washed* and *dried.* Sand prepared in this way can sometimes be obtained in the larger cities, but in most work it is merely screened.

Sea sand is less angular than other sands, and is also considered objectionable on account of the salt contained in it. It should never be used unless thoroughly washed in fresh water. All sands used in plastering mortar require careful screening to take out the coarse particles; and sand for hard finish should be passed through a sieve.

Although the principal use of sand in mortar is to prevent shrinking and to reduce the quantity of lime, it is considered by some, but not by all, authorities to result also in a valuable chemical action and in the formation of a hard silicate of lime, which pervades and strengthens the plaster. (See Article 151.)

In order to make the coarse plaster hang together better, hair or fiber should be mixed with the mortar for the groundwork.

Outside of a few of the large Eastern cities hair has been largely used for this purpose. For several years Manila fiber, chopped into lengths of about 2 inches, has been used instead of hair for ordinary mortar in some cities, especially in the East. Most of the patent mortars contain either asbestos or fiber. Fiber is cleaner than hair and is said to be less injured by the lime.

Most of the hair used by plasterers is taken from the hides of cattle, and is washed and dried and put up in paper bags, each bag being supposed to contain one bushel of hair after it is beaten up.

The weight is generally given as 7 or 8 pounds, but it often falls much short of this.

If obtained from a local tannery, the hair should be thoroughly washed and separated before using.

Hair is generally described in the specifications as "best quality clean, long cattle hair," but the plasterer must take it as it comes in the bags.

Goat hair has been used to some extent in the Eastern States. It is longer and of a better quality than cattle hair.

654. MIXING MORTAR FOR PLASTERING.—The proper mixing of lime mortar comes next in importance to the quality of the lime. The tendency to reduce the cost of building to the lowest possible point, and to shorten the time required for the various operations, has, with other influences, led to much neglect in the mixing of mortar; and it is safe to say that three-quarters of the lime plaster used at the present time is not properly mixed.

Where mortar is mixed by hand at the site of the building, the following method is probably the best that can be considered as practicable:

First, the lime should be thoroughly slaked in a tight box, or, if the lime is not pure, and a residue is left after slaking, it should be run off through a wire sieve into another box and allowed to stand for from twenty-four hours to seven days.

Secondly, after the lime has been slaked the required length of time, the hair should be beaten up and thoroughly incorporated with the lime paste by means of a hoe. The proper amount of sand should then be added and the mixture heaped up in a pile.

Thirdly, after the mortar has stood in the pile not less than seven days, it should be wet up in small quantities to the proper consistency and immediately applied to the lathing, brickwork or other masonry surface.

The ordinary method of mixing plastering mortar is to mix the hair and sand with the lime as soon as it is slaked, and then to throw the mortar in a pile, the whole process occupying but one or two hours. The objection to this method is that the lime is not always thoroughly slaked, and that the hot lime and the steam caused by the slaking burn or rot the hair so as almost to destroy its function, that of strengthening the plaster. For all good work the architect should specify that the lime be slaked at least twenty-four hours before the working in of the hair.

For United States Government work the hair is not mixed in

until the mortar is wet up for putting on. This is a still better, but a rather more expensive method.

If the mortar is required for use in freezing weather it should be made under cover; and under no circumstances should the architect permit the use of mortar that has been frozen.

The mixing of mortar in basements, although sometimes found necessary, is not desirable, as it introduces much moisture into a building. Mortar should never be made in a building when it is practicable to avoid it.

655. MACHINE-MADE MORTAR.—In some cities mortar, for both masonwork and plastering, is made by machinery in buildings specially arranged for the purpose, and delivered at the work in cartloads in a wet and plastic condition, with the hair or fiber, and fresh water incorporated with the lime and sand, ready for use, without the addition of any other material or further manipulation.

The advantages of having the mortar made in this way are that ample time is given the lime to slake, the hair and sand are not mixed with the lime until just before delivery and the mixing is much more thoroughly and evenly done by machinery than is possible by hand.

Using mortar mixed at some other place than in the building permits of finishing the lower stories sooner than could otherwise be done and also does away with the inconvenience of having a large pile of mortar stacked on the sidewalk or in the basement.

Among the earlier buildings using machine-made mortar may be mentioned the Corn Exchange building, the Manhattan Life Insurance Company's building and the Home Life Insurance Company's building in New York City. Since its successful use in these buildings it has been employed in many other large and important structures throughout the country.

The original and typical process of making the mortar in a Philadelphia plant is described as follows:

"Into four slaking machines or revolving pans about twelve bushels of lime are placed and enough water introduced to slake without burning. The pan is started and the lime is kept in motion by a mechanical arrangement of three feet on a perpendicular shaft. When the slaking is complete a plug is removed, and the lime and water carried by a trough through three screens

into a well; from this well it is pumped into vats located in the upper stories of the mixing-house. Screening the lime eliminates all cores or underburned limestone, stones and other foreign matter so injurious to mortar and especially to that used by plasterers.

"When the lime and water are pumped into the vats the mixture much resembles thick milk; and, after standing three weeks, it assumes the consistency of soft cheese. Water is allowed to stand in these vats, which further aids in the slaking of any minute particles that have escaped through the sieves and also prevents the air from reaching the mass. (The lime used contains a considerable amount of magnesia, as a pure carbonate does not give the setting qualities desirable.)

"When mortar is to be made this lime paste is carried to the mixing-pans, which are like those used in slaking, except that they have two sets of feet; sharp, clean bar sand also is placed in the pans, and the machine thoroughly incorporates the lime and sand into a homogeneous mass; not a streak of lime and a streak of sand, but a material of uniform evenness. As a result of this care, I have tested briquettes made of machine mortar and have obtained a tensile stress as great as 52 pounds to the square inch; in twenty-seven or twenty-eight days, out of three briquettes broken, I secured 48, 52 and 50 pounds tensile stress per square inch. We never allow lime to air-slake; neither do we mix the sand with the hot lime and allow it to stand."*

When mixing mortar by hand, the more nearly the process approaches the above order of procedure the better will be the quality of the plastering.

656. PROPORTION OF MATERIALS. (See also Articles 148 and 207.)—It has been found by repeated experiments that a barrel of Rockland lump lime, thoroughly slaked, will yield on an average 2.72 barrels of lime paste. Some limes will yield more and others less, the average of four Eastern limes tested being 2.62 barrels of paste. It has also been demonstrated by repeated experiments that the *average* sum of the voids in sharp, clean, silicious bank or pit sand, taken from different locations and thoroughly screened, is .349 of its bulk. It has been shown also that the *best* mortar is obtained by mixing with the sand an amount of lime paste from 45 to 50 per cent greater than the

* Henry Longcope, in *The Brickbuilder.*

amount needed to fill the voids, which practically requires a proportion of 1 part of lime paste to 2 parts of sand. This is the proportion usually specified on Government work.

As it is difficult to measure the lime paste, it is perhaps better to specify that only 5½ barrels of screened sand shall be used to one cask of lime. Where lime is sold by weight, about the same proportions are obtained by specifying 2½ barrels of sand to 100 pounds of dry lime.

When mixed in the above proportions it requires about 2½ casks, or 500 pounds, of lime and 14 barrels (42 cubic feet) of sand to cover 100 square yards of lathwork ⅜ of an inch thick over the laths.

The proportion of hair to lime should be, for first-class work, 1½ bushels of hair to one cask, or 200 pounds, of lime for the scratch coat, and ½ of a bushel of hair to one cask of lime for the brown coat. This is considerably more, however, than is found in most plasters.

The proportion of lime given above is none too rich for first-class plaster, either for the brown coat or the scratch coat; but it is seldom, if ever, that brown mortar is made as rich as this, and much first-coat work is inferior to it.

In fact, it is almost impossible to regulate the proportion and uniform mixing of common lime plaster. Where lime is sold by the cask it can be done by mixing one cask of lime at a time and measuring the sand; but where lime is sold by weight it is necessary to keep scales on the ground for weighing the lime; and in either case it is necessary to have an inspector to watch the making of the mortar.

In practice the lime is slaked and as much sand mixed with it as the mortar mixer thinks best or the plaster will stand, and it is almost impossible for the architect to tell whether or not there is too much sand. It seldom happens that there is too little sand.

After considerable experience with mortar, one can tell something about its quality from its appearance after it has been "wet up," or by trying it with a trowel; but in most cases the architect and the owner are practically at the mercy of the contractor, and about the best that can be done, when using common plaster, is to insist on the best materials, mixing in the hair after the lime is cool and giving the contract to an honest and intelligent plasterer.

657. PUTTING ON THE PLASTER.—Plastering on lathed work is generally done in three coats.* The first coat is called the "scratch coat," the second the "brown coat" and the third the "white coat," "skim coat" or "finish."

The Scratch Coat.—On brickwork or stonework the scratch coat is generally omitted.

The scratch coat should always be made "rich," and should contain plenty of hair or fiber, as it forms the foundation for the brown coat and white coat. This coat is generally put on from $\frac{3}{16}$ to ¼ of an inch thick over the laths, and should be pressed by the trowel with sufficient force to squeeze it between and behind the laths, so as to form a key or clinch. It is this key which holds the plaster to the laths. When the first coat has commenced to harden (the time varying from two to four days) it should be scored or scratched through almost its entire thickness with lines running diagonally across each other and from 2 to 3 inches apart. This allows the second coat to take a better hold.

The first coat should be thoroughly dry before the second coat is put on, but if the surface is too dry it should be slightly dampened with a sprinkler or brush as the second coat is applied.

A great deal of plastering, sometimes called "green work," is done by applying the brown coat from the same stage used for the scratch coat, and by putting it on immediately after the latter. When done in this way the scratch coat is generally made very rich and the brown coat is made largely of sand, the brown coat being worked into the scratch coat so that it really makes only one coat.

All intelligent plasterers admit that better work results by letting the scratch coat get dry before the brown coat is put on; but as it takes more labor and also more lime to put on the plaster in this way, they will not do it unless it is particularly specified. Besides not making as good a wall, the application of the brown coat to the green scratch coat also causes the laths to swell badly, and this causes cracks in the plastering when the laths dry.

The Brown Coat.—The second or "brown" coat is put on from ¼ to ⅜ of an inch thick. With this coat all the surfaces should be brought to a true plane, the angles made straight, the walls plumb and the ceilings level.

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* In the Eastern States dwellings of moderate cost are generally plastered with two-coat work, the first or scratch coat being brought out nearly to the grounds, and carefully straightened to receive the skim coat.

On walls the plastering can generally be brought to a true plane by means of the grounds, if the latter are set true and if the wall surface is not too large or without openings. On the ceilings, however, there is usually nothing to guide the plasterer in his work, and the consequence is that most ceilings, and particularly those in dwellings, have a *rolling* surface, which is particularly apparent near their edges.

Screeds.—The only way to make ceilings and walls true planes, where the grounds alone are not sufficient, is by "screeding," which is done by applying horizontal strips of plaster mortar, from 6 to 8 inches wide and from 2 to 4 feet apart, all around the room. These are made to project from the first coat to the intended face of the second coat, and while soft are made perfectly straight and out of wind with each other by testing with a plumb and straight-edge. When the screeds are dry the second coat is put on. This fills up the broad horizontal spaces between them, and is readily brought to a true surface in the same plane as the screeds by the use of long straight-edges.

On lathed work, if the studding or furrings have been properly set, screeding should not be necessary except on ceilings; but on brick, stone, tile or concrete walls it is impossible to get true surfaces except by the use of grounds or screeds. Screeding was formerly employed much more extensively than at present; now it is seldom used except in very expensive buildings. Screeding can be done only in three-coat work. Before the brown coat becomes hard it should be lightly run over with the scratcher to make the third coat adhere better. If part of the walls is to be plastered on brickwork and part on laths, the scratch coat is put only on the laths, and when this is dry the brown coat is spread over the whole, including the brickwork. Brick walls that are to be plastered should have the joints left rough or open; and the walls should be cleaned by brushing off all dust and slightly dampened before the mortar is put on. In very dry weather brick walls should be sprinkled with water from a hose just before they are plastered.

The Third or Finishing Coat.—The method of finishing a wall varies somewhat in different parts of the country and varies also with the kind of surface desired. In some localities, particularly in small towns and in villages, when walls are to be papered, no finishing coat is applied, the brown coat or scratch coat being

smoothly trowelled. This, however, reduces the expense but a trifle and is not to be recommended, as the walls cannot be brought as easily to a true plane and the roughness of the plaster shows through the paper.

The Skim Coat.—In many of the Eastern States the finishing coat is called the "skim coat," and is made of lime putty and fine white sand, generally a washed beach sand. The lime is slaked and run through a sieve into a tight box and there allowed to stand until it becomes of the consistency of putty, when it is taken out and the sand mixed with it. The box containing the putty should be kept covered to keep out dust and dirt, and the putty should not be used until it is at least a week old.

The skim coat is put on with a trowel, floated down, and then gone over with a brush and small trowel until the surface becomes hard and polished. In the author's opinion this makes a much better finish than the ordinary "white coat," although it is claimed that the latter is better for walls that are to be painted.

The White Coat.—This term is generally used to designate the finishing coat when plaster of Paris is mixed with the lime putty. In most parts of the United States it appears to be the custom to finish the walls with a thin coat of lime putty, plaster of Paris and marble dust. This makes a wall that is whiter than one finished with a skim coat; and if marble dust is used and the work well trowelled the surface takes a good polish. Without the marble dust it is not so hard and it does not take a polish. For this work the lime is slaked and left to form a putty, as with the skim coat. The plaster and marble dust should not be mixed with the putty until a few minutes before using, and then only as much should be prepared as can be used up at once. If left standing any length of time it "sets" and becomes useless. It should be finished by brushing it down with a wet brush and immediately going over it with a trowel. The more it is trowelled the harder it becomes. In estimating the quantity of materials required for the white coat, 90 pounds of lime, 50 pounds of plaster and 50 pounds of marble dust should be allowed to 100 square yards.

Sand Finish.—When a rough finish is desired for fresco work, as often used in churches, halls, etc., the third coat is mixed with lime putty and sand as for the skim coat, except that coarser sand and a greater quantity of it is used. Sometimes a small quantity

of plaster of Paris also is mixed with it. Sand finish should be applied before the brown coat is quite dry, and should be floated with either clear, soft pine or cork-faced floats. The roughness of the surface desired may be conveniently designated by comparing it with the different grades of sandpaper.

Sometimes the brown coat is floated to give an imitation of sand finish, but it is impossible to get an even and uniform surface without using a separate coat. Sand finish is often ruled off and jointed to imitate stone ashlar. It may also be colored as described in Article 677, "Colored Sand Finish."

658. HARD WALL PLASTERS.—By using only the best materials and mixing them in the manner described it is possible to obtain a very good quality of wall plaster; but there are so many chances of getting an inferior job when ordinary *lime* plaster is used that any material which can be used with greater certainty is very much to be desired. Such materials appear to be found in the *improved* wall plasters placed on the market during recent years.

There are now several improved plasters manufactured by different companies which, although differing in composition, result, apparently, in about the same kind of wall covering.

The general name "hard wall plaster" has been given to these improved or patented wall plasters.

There are two classes of hard plasters: (1) natural cement plasters and (2) chemical or patented plasters.

The term "natural cement" is still used, although the nature of the products is that of gypsum rather than that of hydraulic cement.

659. NATURAL CEMENT PLASTERS.—In this class are such plasters as "Acme," "Agatite," "Royal," etc.

The earth from which these plasters are produced is found in various portions of Kansas and Texas. It is of a light ash-gray color and of about the consistency of hard plastic clay, which it much resembles in appearance, though chemically it is in the nature of an impure gypsum.

When calcined it assumes a pulverized form. When mixed with water the product sets and becomes very hard.

A sample of "Agatite," after several weeks' setting, broke under

a tensile stress of 370 pounds per square inch. It is superior in strength to most of the hydraulic limes and natural cements.*

The various deposits from which the plasters here mentioned are produced appear to be of about the same grade of earth, the plasters differing, if at all, in their strength and working qualities only. This is due principally to slight differences in the process of manufacture.

The "Acme" cement plaster is produced by calcining the natural earth at a high degree of heat (about 350° Fahr.), which rids the material of not only the free moisture, but also of about 75 per cent of the combined moisture.

The resulting plaster, when retarded, sets slowly, works smoothly under the trowel and does not come to its normal strength until dry. It has strong adhesive properties.

"Acme" cement plaster was the first of this class to be put on the market. It has been extensively used throughout the country, and makes a very superior wall plaster. Large quantities of it were used in plastering the World's Fair buildings, Chicago. "Agatite" and "Royal," although more recently introduced, have also been quite extensively used, particularly on large and important buildings in the West.

660. CHEMICAL OR PATENTED PLASTERS.—In this class are such wall plasters as "Adamant," "Granite Hard Wall Plaster," "King's Windsor Cement Dry Mortar," "Paragon Wall Plaster," "Rock Wall Plaster," "Union Wall Plaster," "Victor Wall Plaster," etc.

At the present time most of the hard plasters, and particularly those in the East, are made by mixing plaster of Paris, hydrated lime, hair, asbestos and a sufficient "retarder" to keep the plaster of Paris from setting too quickly. This is for what is known as "neat material."

For "dry mortar" one part of the above compound is mixed with two parts of sand for lath mortar for either wooden lath or metal lath, and with three parts of sand for brick or terra-cotta walls.

In the West the lime is not used to any extent, as it is difficult to prepare it properly; and it is cheaper to make wall plaster in a dry state without the use of lime.

The difference in hard wall plasters really consists in the use or

* Professor Edwin Walters, in Kansas City *Journal*, January 20, 1893.

omission of lime and in the kind of retarder employed to make the plaster of Paris set slowly. The greater number of business houses dealing in plasters now purchase their retarders from manufacturers who make the latter a specialty. All these retarders have practically the same basis and are made from some form of glue stock or saccharine matter.

There is very little to-day that is secret about the manufacture of these plasters.

Among the first of these plasters to be placed on the market was the one known as "Adamant." This material was first introduced in 1886 at Syracuse, N. Y., as a substitute for lime plaster. It is a chemical preparation, and the manufacture of the chemicals was originally covered by patents and the chemicals at first manufactured exclusively in that city by the original company and sold to licensed companies, who prepared and sold the plaster.

Since 1890 many competitors have appeared in the field, each producing materials whose claims have generally met with the approval of architects and builders.

"King's Windsor Cement" is made by mixing certain ingredients with plaster of Paris or calcined plaster, calcined from a superior quality of Nova Scotia gypsum.

"King's Windsor Cement Dry Mortar" is the above composition mixed with the correct portion of washed and kiln-dried bank sand.

In the manufacture of these plastering products all the ingredients are automatically weighed and thoroughly mixed by special machinery, thus insuring the requisite strength and uniformity in both quality and working. It is claimed that no acids are used in their manufacture and that therefore they will not rust nor corrode structural steel, metal lath, etc.

Windsor Cement is manufactured in the Borough of Richmond, New York, N. Y., and has been used extensively in many public and private buildings in that city and to a large extent throughout the Eastern and Middle States.

"Rock Wall Plaster" is manufactured in upper New York City. The different ingredients are selected, weighed and thoroughly weighed by machinery. The product is put up in bags in a dry state and is ready for use when sent to a building, requiring only the addition of water to moisten it before applying it to a wall. It is made from slaked lime, sharp and cleaned kiln-dried sand, with a

proper proportion of plaster of Paris, asbestos and whipped cattle hair.

Rock Plaster differs from other hard wall plasters in being made principally of lime which goes through a process of "aging." This, it is claimed, increases the strength of the plaster as time goes on. It is not as hard as other hard wall plasters are soon after they are put on; but within a month it becomes very hard and continues to improve with age, when properly handled and applied.

"Paragon Wall Plaster" is made in Syracuse, N. Y., and has become widely and favorably known to the building trades. It is made by established formulas, mixed by power and is uniform in its composition. It is free from acids, has little or no tendency to disintegrate and grows harder with age. This same company has recently introduced also a wood fiber wall plaster called "The Twentieth Century Wall Plaster," and containing no sand.

There are other wood fiber plasters.

The "Victor Wall Plaster" (and "Adamant" also) is made in Chester, Pa., and the "Union Wall Plaster" is made in Wilmington, Del.

A preparation called "Granite Hard Wall Plaster" is made in Minneapolis, Minn., and many similar preparations are made by local companies in several localities.

As far as the author has been able to ascertain all of these materials give good results when properly handled.

661. HOW SOLD.—All of the plasters above described are packed in sacks, or bags, holding 80, 100, 125 or 140 pounds each.

"Acme," "Agatite" and "Royal" wall plasters are sold in the form of cement only, and the sand is mixed with the cement as the latter is used by the plasterer.

Two kinds of cement are sold, one mixed with fiber, and known as "fibered cement," and the other without fiber. The fibered cement should be used for the first coat on lathed work, whether of wood or metal. On brickwork or fire-proof tiling, fiber is not required, and the unfibered cement should be used.

The unfibered cement is used also for the second or brown coat and wherever the plaster is to be trowelled down to a smooth, hard surface. Where the plaster is to be finished with a white surface it is necessary to use lime and plaster of Paris (as on lime plaster) over these cements, as they are of a gray color.

"Windsor Cement" is sold in two forms: (1) "Windsor Cement, Neat," which is to be mixed with sand by the local contractor at the work in the proportion of one part of cement to two parts of sand for application on wooden lath or metal lath and of one part of cement to three parts of sand for application on brickwork, terra-cotta or concrete; the cement and sand are thoroughly mixed together before the water is added; (2) "Windsor Cement Dry Mortar," which is ready for immediate use by the addition of water only.

"Rock Wall Plaster," "Union Wall Plaster," "Victor Wall Plaster," "Adamant" and some others are sold both "neat" and mixed with sand, all ready for applying by simply mixing with clean water. Two grades of these plasters also are made, one for applying on wooden or metal lath work and the other for applying on brick, terra-cotta, concrete, etc., the only difference between the two being that the latter contains more sand than the former. All of these plasters are made for furnishing several different kinds of finishing coats and surfaces.

662. APPLICATION.—The method of applying these plasters does not differ materially from that already described for lime mortar, except that the second coat, corresponding to the brown coat, is put on directly after the first coat and finished with the darby instead of with the float. The scratch coat must be left rough and either scored or broomed, so that there will be a sufficient bond between the scratch coat and the brown coats. Being of the nature of plaster of Paris, these mortars *set* instead of drying, and but little water should be used in working them. Only as much material should be mixed as can be applied in one and a half hours, and material that *has commenced to set* should never be remixed.

Clean water only should be used, and the tools and mortar box should be kept perfectly clean and the box cleaned out after each mixing.

When using the hard plasters on wooden laths the laths should be *thoroughly dampened*, or expanded, before the plaster is spread, so that they will not swell after the plaster has commenced to set. Brickwork, stonework, concrete-work and tilework also should be *well sprinkled* before applying these mortars.

Most of the manufacturers of hard plasters recommend that when their plasters are used the laths be spaced only ¼ of an inch apart,

and that ¾-inch grounds be used, claiming that a smaller quantity of their material is required than is the case with ordinary lime mortar.

A gentleman who has had much experience with cement plasters says, however, that "More failures in hard wall plastering result from too thin coats, too weak keys and too weak material (when sold unmixed with sand) than from any other cause.

"To do a good job of hard plastering it is necessary to use a sufficient amount of cement for tensile strength, to secure a good wide key and to put on a good thick coat of the plaster. Where it is spread very thin it is sure to crack and to result in an unsatisfactory wall covering."

For lathwork a better wall will be obtained, although at a slightly increased expense, by putting on ⅞-inch grounds and spacing the laths for a ⅜-inch key.

All of these plasters can be finished with a third coat, as described in Article 657. This coat should in no case be applied until the base is thoroughly dry.

Sand finish should be made as a separate finish at the mills.

Full directions for applying the various grades of these plasters are furnished by the manufacturers, and architects should see that these instructions are carefully and faithfully followed. When they are *improperly applied* these plasters are inferior to ordinary lime mortar.

663. ADVANTAGES IN USING HARD WALL PLASTERS.—The principal advantages gained by the use of these plasters are: uniformity in strength and quality; greater hardness and tenacity; freedom from pitting; less weight and moisture in the building; saving in time required for making and drying the plaster; minimum danger from frost; and greater resistance to fire and water.

Frost does not harm these plasters after they have commenced to set or after chemical action has taken place. When used in freezing weather they must not be allowed to freeze during the first thirty-six hours after applying; after that time frost does no harm.

Those plasters which are already mixed with sand and fiber have the additional advantage also of thorough and uniform mixing of the materials and *absolute correctness of proportions.* This latter advantage is perhaps appreciated most by the architect, as it

prevents all chance of using a poor quality of sand, or too much of it; and it also saves him a great deal of labor in the superintendence.

The benefit to the owner in using these plasters consists in securing much more substantial walls than is possible with the ordinary hand-made mortar, less risk from fire and less expense on account of repairs.

The slight additional expense of using them is hardly to be considered when it is compared with the benefits obtained; and it is probable that these plasters will be still more generally adopted, as they are already extensively used in the largest and most costly buildings.

For mercantile buildings the saving in the time required for drying the plastering more than pays for the additional expense.

On account of their greater density these mortars will not harbor vermin nor absorb noxious gases and disease germs, and they are therefore especially desirable for hospitals, schools, etc. Heat, air and moisture will not pass through them as through lime plaster.

A wall covering of hard plaster on wooden or metal lath is also much more resonant than one of lime mortar, unless equivalent thicknesses of mortar are applied; and for this reason, and also on account of their greater strength, these mortars are valuable for plastering churches, opera-houses and public halls.

664. INTERIOR STUCCOWORK.—This term, as commonly used in this country, refers to ornamental interior plasterwork, such as cornices, moldings, centerpieces, etc. For such work a mixture of lime paste and plaster of Paris is used, except for cast work, which is made entirely of plaster of Paris.

Plaster of Paris is produced by the gentle calcination of gypsum to a point short of the expulsion of the whole of the moisture. Paste made from it sets in a few minutes, and attains its full strength in an hour or two. At the time of setting it expands in volume, and this property makes it especially valuable for taking casts, making cast ornaments for walls and ceilings, and patching and repairing ordinary plasterwork.

When added to lime mortar, plaster of Paris causes the mortar to set or harden very quickly, and for this reason it is often mixed with mortar to be used for patching or repairing. Work of this kind is called "gauged work."

Plaster of Paris is very apt to crack when used clear or "neat," and when its thickness is considerable. Cast ornaments made of it are therefore usually made hollow or with a thin shell. For work that is to be run, or worked by hand, it cannot be used neat, as it sets too quickly. It is for this reason that lime putty is mixed with it.

For moldings, cornices, etc., a mixture of about 2 parts of plaster of Paris to 1 part of lime paste is used.

Plain moldings, whether in a cornice or centerpiece, or on a wall or ceiling, are usually run in place by hand. The process consists in spreading on the surface of the wall or ceiling a sufficient body of plaster and in forming the mold by running along it a sheet-iron template, cut to the reverse profile of the mold. This template is stiffened by wooden cleats and provided with struts to keep its plane always perpendicular to the plane of the surface on which the mold is run. The stuccowork is always run before the finishing coat of plaster is applied, as it is necessary to fasten light pine straight-edges on the walls to form guides for the templates. In running the molding two men are generally required, one to put on the plaster as it is needed and the other to work the template, which generally has to be worked back and forth several times before the molding is finished.

The whole molding or cornice between any two breaks or projections should be completed at once, so that the entire length may be uniform in shape and shade.

The miters at the angles, both internal and external, have to be finished by hand by using a small trowel and a straight-edge.

If the cornice or molding contains much ornamental work it is cheaper to cast it in sections, each about 2 feet in length, and attach it to the wall by means of liquid plaster of Paris. Great care is required in cast work to join the sections so that the lines of the moldings will be perfectly straight.

If there are only one or two enriched members the rest of the molding or cornice may be run in the usual way, leaving sinkings to receive the enriched members, which are then cast and stuck in place, as at *A*, Fig. 623.

In designing cornices or belt-moldings care should be taken to have not more than a 3-inch thickness of plaster at any point. If the moldings require a thickness of material greater than this the

wall or angle should be blocked and lathed, as in Fig. 623, so as to reduce to a minimum the amount of plaster required. When the projection is only about 3½ or 4 inches the back may be formed of brown mortar (Fig. 624), containing a little plaster of Paris, and held in place by projecting spikes or large nails driven into the wall or ceiling before the mortar is put on.

Center ornaments consisting of plain circular moldings only are run in the same way as other molded work, except that the template is attached to a piece of wood which is pivoted at the center of the ornament. Enriched centers are cast in a mold and stuck to the ceiling after the finishing coat is on.

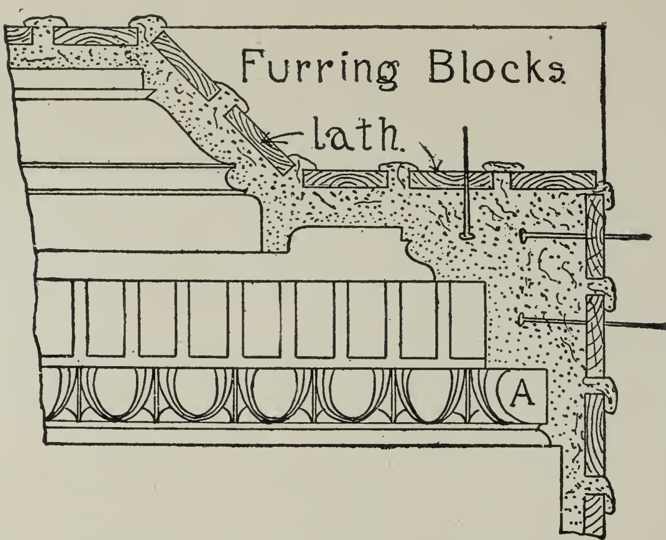

Fig. 623. Interior Stucco Cornice, Blocked and Lathed.

All kinds of ornaments, such as panelled ceilings, bas-reliefs, imitations of foliage, etc., may readily be executed in plaster of Paris; and when the ornaments are placed in such positions that they cannot be injured by objects in the room, it answers as well as harder and more expensive materials.

Since hardwood finish has become so common, however, it has largely supplanted the plaster cornices that were so much used up to about the middle of the last century.

Stuccowork is generally included in the plasterer's specifications. As it is much more expensive than ordinary plastering, the quantity

and character of it should be clearly indicated on the drawings and in the specifications and by full-size details.

For enriched work the architect should require that the models be approved by him before the casts are made.

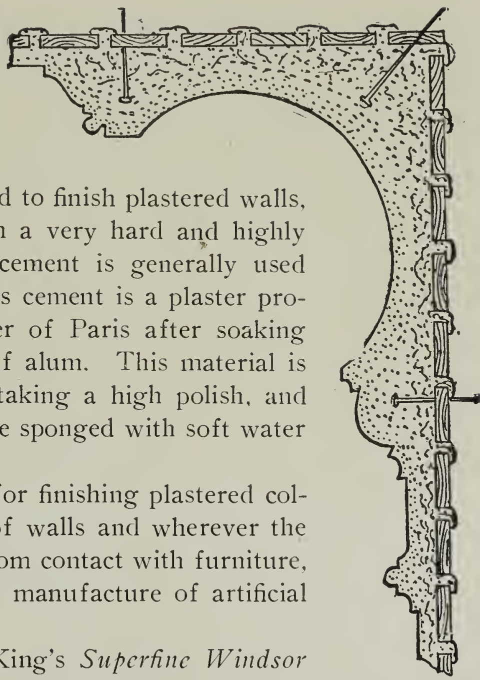

Fig. 624. Interior Stucco Cornice. Small Projection.

665. KEENE'S CEMENT.—When it is desired to finish plastered walls, ceilings, columns, etc., with a very hard and highly polished surface Keene's cement is generally used for the finishing coat. This cement is a plaster produced by recalcining plaster of Paris after soaking it in a saturated solution of alum. This material is very hard and capable of taking a high polish, and walls finished with it may be sponged with soft water without injury.

It is especially valuable for finishing plastered columns, the lower portions of walls and wherever the plaster is liable to injury from contact with furniture, etc. It is also used in the manufacture of artificial marble.

The manufacturers of King's *Superfine Windsor Cement* and of some other materials of a similar nature claim that for finishing walls it is equal to the imported Keene's cement. It is considerably less expensive.

On account of their solubility none of these materials should be used in situations greatly exposed to the weather.

666. SCAGLIOLA is a coating applied to walls, columns, etc., to imitate marble. The name is derived from "Scaglia," the rock from which the ancient Italians made their plaster. The base or groundwork is generally of mortar made of good plaster of Paris and clean sharp torpedo sand containing a large proportion of hair. After this has set and is quite dry it is covered with a floated coat, consisting of plaster of Paris or Keene's cement, mixed with various coloring matters in a solution of glue, to give greater solidity and to prevent the plaster of Paris from setting too quickly. When the surface is thoroughly hard it is rubbed with pumice-stone and

Scotch-hone and then rubbed until it looks like polished marble. Columns are made in this way which are with difficulty distinguished by the eye from marble.

Imitation marble, when in flat slabs, is commonly made on sheets of plate-glass. Threads of floss silk, which have been dipped into the veining colors, previously mixed to a semi-fluid state with plaster of Paris or Keene's cement, are placed upon a sheet of plate-glass so as to resemble the veins in the marble to be imitated. Upon this the body color of the marble is placed by hand. The silk is then withdrawn and dry plaster of Paris is sprinkled over to take up the excess of moisture and to give the whole the proper consistency. A backing of Keene's cement or plaster of Paris of any desired thickness is then applied. Canvas is sometimes placed in the backing to give it greater strength. After removal from the glass the slab is polished and set in place in the same manner as the genuine material. This work naturally requires much skill as well as practice and experience on the part of the workmen.

A great deal of scagliola has been used in Europe, and in recent years several companies have been formed in America for making artificial marble. For interior work scagliola should be as durable as marble, and there are columns of it in Europe several hundred years old. It should not be used on the exterior of buildings, as it will not bear exposure to the weather.

In the newer improved processes of manufacture great advances have been made. In fact the newer marbles cannot be made by the old scagliola methods. Any marble can now be imitated by the newer processes, and in all imitated marbles the *artist* is the main thing, the process being really of secondary consideration.

In some of the best of the recent works Keene's cement is used for body and face and also for setting, no Portland cement, plaster of Paris or hard wall plasters being used.

Imitation marbles are made into architectural designs, slabs of any size, moldings of any form, columns of any dimensions, pilasters, pedestals, wainscotings, altars, mantels, etc.

667. FIBROUS PLASTER.—This consists of a thin coating of plaster of Paris on a coarse canvas backing stretched on a light framework and formed into slabs. For casts, about ¼ of an inch of plaster is put in the mold and the canvas then put on the back and slightly pressed into the plaster. Fibrous plaster is very

light and strong, and can be easily handled without breaking. It is extensively used in England for ornamental work, and in Brazil it is said to be used extensively for exterior work.

668. CARTON-PIÈRRE.—This is a material used for making raised ornaments for wall and ceiling decoration. It is composed of whiting mixed with glue and the pulp of paper, rags and sometimes hemp, which is forced into plaster or gelatine molds, backed with paper, and then removed to a drying-room to harden. It is much stronger and lighter than common plaster of Paris when made into ornaments, and is not so apt to chip or break when struck.

Ornaments of carton-pièrre, under different names, are now extensively used in this country for decorating rooms, making mantels, etc., and also to some extent on the exterior of buildings. If kept painted there appears to be no reason why it should not last for many years, except when placed in very exposed positions.

669. EXTERIOR PLASTERING.—This is generally either "rough-cast" or stuccowork. The first is a kind of coarse plastering generally applied on laths; the second is plastering on brickwork executed so as to resemble stone ashlar.

Rough-cast has been extensively used in Canada and to some extent in the Northern States. It is said to be much warmer than siding or shingles, less expensive and quite as durable. It is also more fire-resisting.

"There are frame cottages near the city of Toronto, Canada, and along the northern shores of Lake Ontario which were plastered and rough-casted on the outside over forty years ago; and the mortar to-day is as good and as sound as when first put on, and looks as though it is good for many years to come provided the timbers of the building it preserves remain sound.

"It is quite a common occurrence in the winter in Manitoba and the Northwest Canadian Territories to find the mercury frozen; yet this intense cold does not seem to affect the rough-casting in the least, although in many cases it chips bricks, contracts and expands timber and renders stone as brittle as glass."*

Frame buildings to be rough-casted should be covered with sheathing and one thickness of tarred paper. The partitions should be not only put in but also lathed before the outside is plastered, as it is important to have the building stiff and well braced.

* "Rough-casting in Canada," by Fred. T. Hodgson, *Architecture and Building*, March 24, 1894.

The most approved procedure for rough-cast work, as practiced in the lake district of Ontario, is said to be as follows:

The laths should be No. 1 pine laths, placed diagonally over the sheathing or tarred paper, keeping 1½-inch spaces between the laths. Each lath should be nailed with five nails and joints should be broken every 18 inches. A second covering of laths should be laid diagonally in the opposite direction, keeping the same space between the laths and breaking joint as before. Careful and solid nailing is required for this layer of lathing, as the permanency of the work depends to some extent on this portion of it being honestly done. The first coat should consist of rich lime mortar, with a large proportion of cow's hair, and should be mixed at least four days before using. The operator should see to it that the mortar be well pressed into the keys or interstices of the lathing to make it hold thoroughly. The face of the work should be well scratched to form a key for the second coat, which must not be put on before the first or scratch coat is *dry*. The mortar for the second coat is made in the same way as for the first coat, and is applied in a similar manner, except that the scratch coat is well dampened before the second coat is put on, in order to keep the second coat moist and soft until the dash or rough-cast is thrown on.

The "dash," as it is called, is composed of fine gravel, washed clean, freed from all earthy particles and mixed with pure lime and water until the whole is of a semi-fluid consistency. This is mixed in a shallow tub or pail and is thrown upon the plastered wall with a wooden float about 5 or 6 inches square. While the plasterer throws on the rough-cast with the float held in his right hand, he holds in his left a common whitewash brush, which he dips into the dash and with which he brushes over the mortar and rough-cast, giving them, when finished, a regular uniform color and appearance.

For 100 yards of rough-casting, done as above described, the following quantities are required: 1,800 laths, 12 bushels of lime, 1½ barrels of best cow hair, 1¾ yards of sand, ¾ of a yard of prepared gravel and 16 pounds of cut lath nails 1¼ inches long. A quarter-barrel of lime putty should be mixed with every barrel of prepared gravel for the dash which may be colored as desired by using the proper pigments.

To color 100 yards in any of these tints named the follow-

ing quantities of ingredients should be used: For a blue-black, 5 pounds of lampblack; for buff, 5 pounds of green copperas, to which should be added 1 pound of fresh cow manure, strained and mixed with the dash. A fine terra-cotta color is made by using 15 pounds of metallic oxide, mixed with 5 pounds of green copperas and 4 pounds of lampblack. Many tints of these colors may be obtained by varying the quantities given. The colors obtained by these methods are permanent; they do not fade nor change with time or atmospheric variations. Earthy colors, like Venetian red and umber, soon fade and have a sickly appearance.

Expanded-metal, perforated, or stiffened wire lathing are undoubtedly better than wooden laths for external plastering, as they hold the plaster better and also afford greater protection from fire. The following description of external plastering, as used by an architect of considerable experience with this sort of work, was published in *The Brickbuilder* for August, 1895, and represents probably the best current practice in this country:

"I always use three-coat work, the first coat being well-haired mortar with one-third Portland cement added when ready for use. This coat is well scratched. The second coat is the same, with the omission of the hair; and the third coat has the same proportions, but has coarse sand or gravel, either floated or put on as slap-dash, according to the kind of finish I wish to obtain.

"I occasionally use a very small quantity of ochre in this last coat, but it has to be mixed very thoroughly and carefully in order to produce an even color.

"This plasterwork I have applied on wood lath over studs and without rough boarding behind it. I have applied it also over rough boarding, furring and wood lath, which is a better construcion. When applied over rough boarding, furring and wire lath it makes the best construction of all.

"A small church plastered in this way on wood lath in 1881 is in perfect condition to-day, and various houses built during the last ten years have proved perfectly satisfactory. I have not as yet, however, found any method of building true half-timbered work and of making it thoroughly tight without constructing a wall that is practically as expensive as a brick wall."

670. EXTERIOR STUCCOWORK.—Exterior plastering of buildings was at one time greatly in vogue in European countries,

and there are many examples in those portions of the United States which have the oldest buildings. Lime and sand were formerly used for the purpose, but this mixture is not very durable. If it is desired to plaster a brick building to imitate stone ashlar, Portland cement is the only material that should be used. It should be mixed with clean sharp sand which is not too fine, in the proportion of 3 parts sand to 1 part of cement. The walls to be covered should themselves be dry, but the surface should be well wet down with water from a hose to prevent it from at once absorbing all the water in the cement. The surface should be sufficiently rough, also, to form a good key for the cement. Screeds may be formed on the surface, and the cement mortar applied in one coat of uniform thickness throughout. When cement mortar is put on in two or three coats, whether in exterior or interior work, a coat already applied should on *no account be allowed to dry* before a succeeding coat is added. When this drying takes place the layers are quite sure to separate.

The manufacturers of "Acme" cement plaster claim that where brick buildings are to be plastered on the outside with cement their plaster is superior to Portland cement mortar for the first coat, as it adheres more firmly to the bricks, and holds together the Portland cement and the base upon which it is spread.

Before it becomes hard the cement may be marked with lines to represent stone ashlar. If it is desired to color the cement, mineral pigments, such as Venetian red or the ochres, must be used. The natural color of the cement may be lightened by the addition of a very little lime.

671. STAFF.*—Staff, a material used for the exterior covering of all the buildings of the World's Columbian Exposition at Chicago in 1893, and for most of the buildings of the expositions held since then, may be considered as a comparatively new material in this country, although it has been in extensive use in Europe for many years. A large part of all exterior decoration of buildings, both public and private, in the provincial cities of Germany, whether ornament, columns or statuary, is made of staff; and in some instances a period of fifty years of existence testifies to its enduring qualities. Staff was first used extensively in the construction of

* The following description of this material is taken from an article by Mr. E. Phillipson, published in the *Engineering Record* of June 4, 1892. Mr. Phillipson had charge of this portion of the work on the Chicago World's Fair buildings.

buildings at the Paris Exposition of 1878, and it was also adopted in work on the much larger and grander buildings of the exposition of 1889. The methods of application at these expositions were, however, widely different from and much more expensive than those employed at the Columbian Exposition in this country.

The staff for the World's Fair buildings was made on the grounds at Jackson Park, Chicago, in the following manner:

The ingredients were simply plaster of Paris, or Michigan plaster, water and hemp fiber. Hemp was used to bind together and add strength to the cast, and the New Zealand fiber was preferred, as both the American and Russian fibers were found to be too stiff. The first step in making staff ornaments is the creation of a clay model. The model is heavily coated with shellac, and a layer of clay separated from the model by paper is put on its face and sides. This layer of clay is oiled or greased and a heavy coating of plaster and hemp is put over it. The thickness of this coating is dependent upon the size of the model; sometimes it is 5 or 6 inches thick* and contains heavy battens of wood to strengthen it. In less than twenty-four hours this coating is hard and is taken off the clay covering the model. The coating thus removed is called the box.† After this the clay is removed from the model and the model is thoroughly oiled. The box is oiled and put over the model, leaving the space between model and box, formerly taken up by the clay coating, a free space. Holes have previously been made in the box, and over a large center hole (sometimes over two or three, in large pieces) a plaster funnel is placed. Through these funnels is poured molten gelatine, which fills every space, air being allowed to escape through small holes in the box. In from twelve to twenty-four hours the box is again removed, placed hollow side up, and the now hardened gelatine is removed from the clay model and placed in the box, which it fits perfectly. The clay model has now served its purpose, for the gelatine, which has become a matrix of the cast desired, is used in the further stages of the work. In case of large molds the gelatine matrix is sometimes cut into as many as eight pieces. All these, of course, join perfectly in the box and are cast from it as if from a single matrix. The gelatine mold is washed a number of times with a strong solution of water and alum, and after oiling is ready for the operation of casting.

* It is generally 1 or 2 inches thick.
† The term "case" is now better understood in the trade.

The plaster for the staff is thoroughly stirred in water, and the hemp, cut into lengths of from 6 to 8 inches, is bunched loosely, saturated with the plaster and put in the molds in a layer of about 1 inch in thickness. Succeeding handfuls of hemp are thoroughly interwoven with the preceding, the hemp being expected to fill in all the corners of the cast. When the mold is filled the back is smoothed over by hand, and later the cast is removed from the mold. The time consumed from starting a cast to removing it from the mold is about twenty-five minutes for a cast 5 feet by 2 feet 6 inches in size. After the removal of the cast care must be exercised that it does not collapse nor lose its form by warping either in standing it up or in laying it down. During the summer months a cast of the dimensions given will dry thoroughly in about thirty-six hours and is then ready for application. In the winter months there is danger of casts freezing before they are dry, and in that event they are apt to go to pieces when warm weather comes. A good workman can make as many as seventy-five casts in one mold, and then the gelatine is remelted and a new mold made of it, the box being good for use for an indefinite length of time. In making pilasters or moldings, etc., not ornamental or under-cut, plaster and wood molds are often used, the latter material being especially preferred, owing to its durability.

Applied to a frame building, staff is simply nailed on to the rough construction, and a cheap brick wall covered with it can, at a comparatively small expense, be made to assume a "classic" appearance. In building a brick house with the employment of staff in view, it is advisable to insert wooden furring strips in the brickwork, as these simplify the labor of putting it on. For cornice work it is claimed that strength and boldness of design are possible with staff which cannot be realized with other materials.

At the Paris Exposition the buildings were constructed almost entirely of iron, and nearly all the staff was cast in panels, which were set in iron frames. While this method was considered excellent, both in finished effect and in durability, it was far too expensive and tedious to be employed in covering the much more extensive structures to be built for the World's Columbian Exposition in the United States. Accordingly, after many weeks of study, the construction department decided to construct the buildings of wood and to nail the staff directly to the furring.

The name "staff" properly applies to material that is cast in molds, and not to ordinary plaster or cements that are put on with a plasterer's trowel. Work with such materials is subject to well-understood limitations by the temperature and weather, but atmospheric influences have practically no effect upon staff. This has been demonstrated by the acres of staff that have been standing all winter outside the various casting shops in Jackson Park. No attempt has been made to keep off the rain, snow or frost. Several pieces of it have been submerged for over a month at a time, allowed to freeze and thaw, and freeze again with the water, and when taken out they were found to be perfectly intact.

While this material admirably answered its purpose on the Fair buildings, it deteriorated considerably, and evidently would not answer in such a climate for permanent buildings unless kept well painted. In fact, it appears to be generally conceded that Portland cement mortar is about the only material that will endure permanently under the trying condition of our northern climate. In warmer and dryer climates compositions of plaster are largely used on the exterior of buildings, and in many instances they have lasted for centuries.

The cost of *"staff,"* as used on the Chicago World's Fair buildings, varied from $2 to $2.25 per square yard. Ordinary cement mortar applied directly to the walls cost about thirty cents per yard.

672. WHITEWASHING.—Although not properly belonging to the plasterer's trade, this work is often included in the plasterer's specifications.

Common whitewash is made by simply slaking fresh lime in water. It is better to use boiling water for slaking. The addition of 2 pounds of sulphate of zinc and 1 pound of common salt for every half-bushel of lime causes the wash to harden and prevents its cracking. One pint of linseed oil, added to a gallon of whitewash immediately after slaking, adds to its durability, particularly for outside work. Yellow ochre, lampblack, Indian red or raw umber may be used for coloring matter if desired.

Whitewash not only prevents the decay of wood, but conduces greatly to the healthfulness of all buildings, whether of wood or stone. It does not adhere well, however, to very smooth or non-porous surfaces. Two coats of whitewash are required on new work to make a good job.

673. LATHING AND PLASTERING IN FIRE-PROOF CONSTRUCTION.—The lathing used in fire-proof construction has been described in Article 479 and the immediately following articles. Metal laths and the plastering on the same are also described in Article 649. Plasters as fire-resisting materials are treated of in Article 410. Lath-and-plaster coverings for columns are discussed in Article 419. Metal-and-plaster partitions are described in Articles 472 to 478, metal wall furring in Article 486 and furring for architectural forms in Article 487.

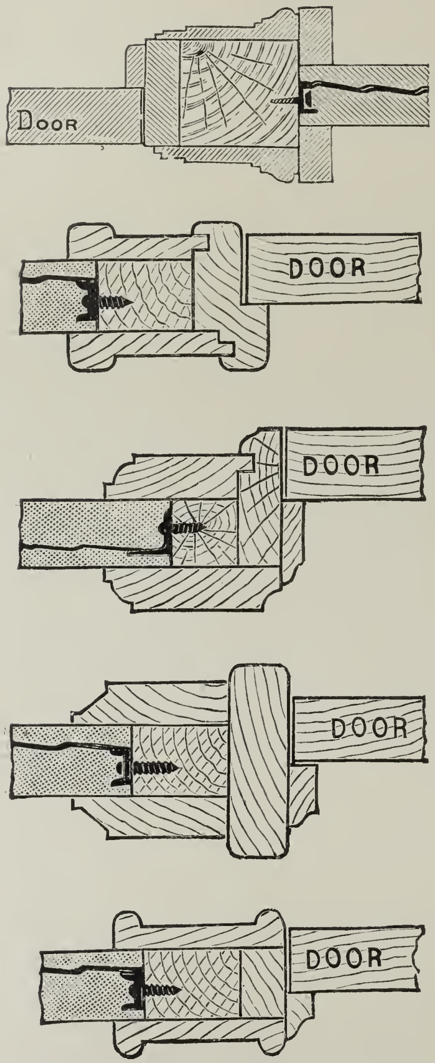

Fig. 625. Door Frames in Metal Lath and Plaster Partitions.

674. FRAMES IN METAL LATH AND PLASTER PARTITIONS. (See also Articles 472 to 478.) —The usual method of framing for doors and windows has been to set up rough wood frames, to which the adjoining channel is securely fastened by screws or anchor nails, and in many cases this method is quite satisfactory.

Fig. 625 shows various styles of door frames, which differ principally in the character of the finish. Those sections which have the widest door jambs are found to be the stiffest. Various modifications of these details may be made to suit the judgment or taste of the architect.

Fig. 626 shows one method of constructing the window frames

in corridor partitions. The style of molding may be varied to suit the taste of the designer.

In warehouses where there is to be heavy trucking, or where iron or fire-proof doors are to be used, the door frames may be built of $1\frac{1}{2}$ by $1\frac{1}{2}$-inch angle-irons, to which the first stud of the partition should be rivetted.

In extremely large doorways and on freight elevators it is often the custom to make the frames of heavy 2-inch channel-irons, to which are hung the large fire-proof doors.

675. MEASURING PLASTERWORK.—Lathing is always figured by the square yard and is generally included with the plastering, although in small country towns the carpenter often puts on the laths.

Plastering on plain surfaces, such as walls and ceilings, is always

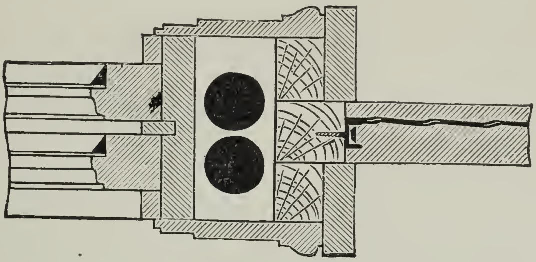

Fig. 626. Window Frame in Metal Lath and Plaster Corridor Partition.

measured by the square yard, whether it be one, two or three-coat work, or whether it be lime or hard plaster.

In regard to deductions, for openings, custom varies somewhat in different portions of the country, and also with different contractors. Some plasterers allow one-half the area of openings for ordinary doors and windows, while others make no allowance for openings of less than 7 square yards.

Returns of chimney breasts and pilasters and all strips less than 12 inches in width should be measured as if 12 inches wide. Closets, soffits of stairs, etc., are generally figured at a higher rate than are plain walls or ceilings, as it is not as easy to get at them. For circular or elliptical work, domes or groined ceilings, an additional price is charged. If the plastering cannot be done from tressels an additional charge must be made for staging.

Stucco cornices or panelled details are generally measured by the

superficial foot, measuring on the profile of the moldings. When less than 12 inches in girth they are usually rated as 1 foot. For each internal angle 1 lineal foot should be added, and for external angles 2 feet.

For cornices on circular or elliptical work an additional price should be charged.

Enriched moldings are generally figured by the lineal foot, the price depending upon the design and size of the molding.

Whenever plastering is done by measurement the contract should state definitely whether or not openings are to be deducted; and a special price should be made for the stuccowork, based on the full-size details.

676. QUANTITIES OF MATERIALS AND COST OF PLASTERWORK.—The cost of lime plastering on plain surfaces, including wooden laths, varies from thirty to fifty-five cents per

Description of Work.	Average cost in cents per square yard.	
	New York.	St. Louis.*
Lime Mortar:		
[1] Two-coat work on brick or tile	30 to 40	25
[1] Three-coat work on wood laths	45 to 55	25 to 35
[1] Three-coat work on stiffened wire lath [3]	70	..
[1] Three-coat work on expanded metal [3]	..	60
[2] Rock Plaster, Windsor Cement or Adamant on brick or tile	40	..
[2] Acme or Royal cement plaster on brick or tile	40	25 to 30
[2] Windsor Cement or Adamant on stiffened wire lath [3]	75	..
[2] Rock Plaster, Acme or Royal cement plaster on stiffened wire lath [3]	75	65
Cost of stiffened wire lath on wood joists, about	35	..
Cost of expanded metal on wood joists	25 to 35	35
Cost of Bostwick last on wood joists	25 to 35	35
Stucco cornices, less than 12 inches girth, per lineal foot	20 to 40	20 to 40
When more than 12 inches girth, cost per square foot	25 to 30	25 to 30
Enrichments cost from 8 cents up, per lineal foot, for each member.		

[1] The last coat to be white finish.
[2] Finished with lime putty and plaster.
[3] When applied on wood joists or furring: when applied over metal furrings the cost is about 20 cents per yard more. The price includes the cost of the metal lath.

yard, according to the times, locality, number of coats and quality of work. For ordinary three-coat work, with white finish, thirty-five or forty cents is probably about the average price for the entire country. The author has known at various times in the past very good work to be done for twenty cents per yard, but at that price there was no profit above the wages of the men.

Hard plasters cost from two to ten cents per yard more than

* These prices are about the average asked in the West.

lime plaster, according to the price of lime and the freightage on the hard plaster.

Wire lathing or metal lathing costs from twenty-five to forty cents per yard more than the cost when wood laths are used.

The figures in the table on the preceding page give the average prices for various kinds of plastering in the cities of New York and St. Louis, subject to variations from year to year:

For the scratch coats and brown coats on wood laths, with ¾-inch grounds, the following quantities of materials are required for 100 square yards: From 1.400 to 1,500 laths, 10 pounds of threepenny nails, two and one-half casks or 500 pounds of lime, 45 cubic feet or fifteen casks of sand and four bushels of hair.

For the best quality of white coating allow 90 pounds of lime, 50 pounds of plaster of Paris and 50 pounds of marble dust.

It is impossible to quote prices which will hold for the many different parts of the United States, and those given are only approximate. They give some idea, however, of relative values. The following data* relating to quantities of materials and cost of lathing and plastering are added. They include some of the items already given, and vary in some particulars, being compiled from other sources.

Quantities of Materials Required for Lathing and Plastering.— To cover 100 square yards requires from 1,400 to 1,500 laths (about 1,450 for an average job) and 10 pounds of threepenny nails.

Three-coat plastering on wood laths, plaster of Paris finish, requires from 8 to 10 bushels of lime, 1½ yards of sand, 2 bushels of hair and 100 pounds of plaster of Paris per 100 square yards.

If the finishing coat is omitted deduct 2 bushels of lime and all of the plaster of Paris.

If a sand-finish is required omit the plaster of Paris and add ½ a yard of sand.

Two coats on brick or stone walls (brown coat and finishing coat) require from 6 to 8 bushels of lime, 1½ yards of sand and 100 pounds of plaster of Paris to 100 square yards.

Best's Keene's cement for brown mortar and Keene's finish on expanded-metal lath requires, for the brown mortar, 550 pounds of cement, 5½ bushels of lime, 2 yards of sand and 2 bushels of

* Taken from Part III of the "Architect's and Builder's Pocket-Book." Frank E. Kidder.

hair; and for the finish, 300 pounds of cement and 1 bushel of lime per 100 yards.

Hard plasters on expanded-metal lath, plaster of Paris finish, require for the brown mortar 2,000 pounds of plaster and 2 yards of sand; for the finish, 1 bushel of lime and 100 pounds of plaster of Paris per 100 yards.

Cost.—The standard price for putting on wood laths (labor only), in Denver, is 3¾ cents per yard. For expanded-metal or sheet-metal lath on wood studding, 5 cents; on steel studding, wired, 8 cents.

The cost of putting three coats on laths, plaster of Paris finish (labor only), is about 15 cents per yard for drawn work and 16 cents for dry scratched work.

For sand finish the cost is about the same as for white finish.

These figures are based on plasterers' wages at 62½ cents per hour and on hod-carriers' and mortar-mixers' wages at 37½ cents per hour.

The following table gives the average cost of different kinds of plastering in Denver, based on Missouri lime at 40 cents per bushel, sand at 75 cents per load of 1¼ yards, hair at 40 cents per bushel, plaster of Paris at 50 cents per 100 pounds and wages as given above:

Scratch and brown coat (lime) on wood laths..	25	cents	per	yard.
3 coats (lime) on wood laths, plaster of Paris finish..............	30	"	"	"
3 coats (lime) on wood laths, sand finish.......	30	"	"	"
Brown coat and finish on brick walls.........	23	"	"	"
For hard wall plaster instead of lime, add.....	3	"	"	"
3 coats (lime), plaster of Paris finish, metal lath on wood studding.....................	65	"	"	"
3 coats (lime) plaster of Paris finish, metal lath on steel studding........................	68	"	"	"
For Keene's cement finish, add.........	10	"	"	"
For blocking in imitation of tile, add....	50	"	"	"
2 coats hard wall plaster, plaster of Paris finish, metal lath, wood studding...............	70	"	"	"
2 coats hard wall plaster, plaster of Paris finish, metal lath on steel studs................	73	"	"	"
For Keene's cement finish, add.........	10	"	"	"

Portland cement, brown coat, finished with Keene's cement blocked in imitation of tile, 3 by 6 inches...........................	$2.80 per yard.
For running base, 9 inches high, in Best's Keene's cement	10 cents per foot.

For running plain moldings in plaster of Paris, from 3 to 5 cents per inch of girth.

For finishing shafts of columns, from 16 to 24 inches in diameter and from 12 to 14 feet in height, $3.00 per column (labor only).

These prices are believed to be pretty nearly an average for the entire country. In some localities prices for materials or labor are less, in others more.

677. COLORED SAND FINISH.—In most instances where sand finish is used on interior walls, it is for the purpose of afterward decorating with water colors. In such cases the finish itself may be colored or stained at a slightly less expense than is required for water colors. When the finish is stained throughout its entire mass, dents and scratches do not show, as they do in the case of paint or kalsomine. For coloring sand finish, pulp stains of the best quality should be used. These are mixed with water to the consistency of a thick cream and then thoroughly mixed with the finishing material, all the mortar for one room being mixed at one time, so that the color will be uniform. No plaster of Paris should be used in colored sand finish, as it will streak the wall. Dry colors also should not be used, as they are quite sure to prove a failure. (See also Article 657, under "Sand Finish.")

678. SUPERINTENDENCE OF LATHING AND PLASTERING.—This consists chiefly in seeing that the work is performed in accordance with the specifications; and if the specifications are properly written much of the vexation of superintendence is saved. The details which the superintendent should particularly inspect are the following:

Quality of Materials.—See that the laths are of the kind specified, and, if of wood, that they are free from bark and dead knots. If any such laths have been put on have them removed and have clean, sound laths substituted. See that the lime is of the kind specified; if it is not in casks it is well to require the plasterer to produce the bills for it; also see that the lime is fresh and in good condition. Permit no lime that has commenced to slake to be

used. Inspect the sand to see that it is free from earthy matter, and that it is properly screened. Make a note of the time when the plasterer commences to make the mortar, and do not permit him to use it until it is at least seven days old, or as old as required by the specifications.

As to the proportions of the lime, sand and hair, not much can be determined by the superintendent, unless he has the quantities measured in his presence, a proceeding which requires his being on the ground most of the time. Something, however, of the quality of the mortar and of the amount of hair may be determined by trying the former with a trowel. The superintendent should endeavor to make himself familiar with the appearance of good mortar. He should see that the hair is mixed with the mortar at the stage specified, and should in no case permit it to be mixed with the hot lime.

Lathing.—Before the workmen commence to put on the laths the architect or superintendent should carefully examine all grounds and furring to see that they are in the right place and that they are plumb and square. If the chimney-breasts are furred, as they usually are in the Eastern States, they should be tried with a carpenter's square to make sure that their external and internal angles are right-angles; and to see also that all angles of adjoining partitions are made solid, so that there can be no lathing through these angles.

If wooden laths are used see that they are well nailed and that they are not placed too near together; 3/8 of an inch should be allowed on ceilings and from 1/4 to 5/16 of an inch on walls.

See that the end joints are broken at least every 18 inches; or, better still, have the joints broken at every course.

See that the laths over door and window heads extend at least to the next stud beyond the jamb (as in Fig. 627), so as to prevent cracks which are apt to appear at that point; see also that all the laths run in the same direction. When laths run in different directions (as in Fig. 628) cracks are sure to appear where the change in direction takes place. See that all recesses in brick walls for pipes, etc., are covered with wire lath or expanded-metal lathing, unless they are to be covered with boards.

See that all wood lintels and other solid timbers that are not furred are covered with metal lath. The joints also between wood-

work and brickwork should be covered with metal lathing. If any kind of metal lathing is used see that it is put up as directed by the manufacturers, and that all wire lathing is tightly stretched; see that the furrings are properly spaced and that the whole is well secured.

Closing the Building.—Before the plasterers commence work the superintendent should see that the building is closed up by the carpenter, by filling the openings with boards, old sashes or cloth. Cotton cloth is the best material for the purpose, as it allows some circulation of air through it.

Heating the Building.—If the plastering is done in cold or freezing weather provision must be made for heating the building. Ordinary lime plaster is completely ruined by freezing and thawing,

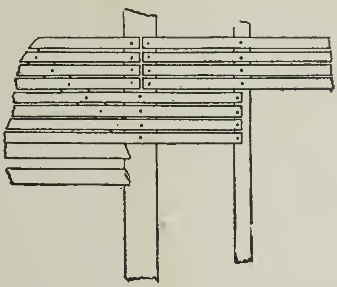

Fig. 627. Lathing Over Door or Window Head.

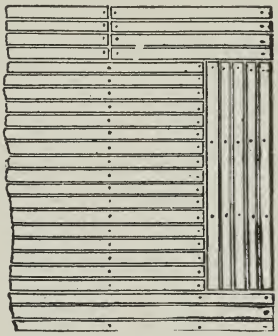

Fig. 628. Lathing Run in Two Directions. Poor Construction.

and plastering that has been once frozen will never become hard and solid.

Plastering.—When the scratch coat is partly on, the superintendent should try to look behind the laths to see if the mortar has been well pushed through between them, as the clinch, or key, at the back of the laths is all that holds the plaster in place.

See that the first coat is dry before the second is put on, if so specified; see also that the surface of the brown coat is brought to a true plane, the angles made straight and square, the walls plumb and the ceilings level. The specifications should require that the first and second coats be carried to the floor, behind the base or wainscoting.

When brick walls are to be plastered the superintendent should

remember that a much firmer job of plastering will be obtained if the wall is well wet just before the plastering is applied.

If the first and second coats have been properly put on the finishing coat will need little superintendence beyond seeing that proper materials are used and that the work is well trowelled, if it is to be a hard finish.

If any of the improved plasters described in Articles 658 to 663 are used the superintendent should see that the instructions furnished by the manufacturers are strictly followed, particularly as to the wetting of the laths and the proportion of sand to be used; he should see also that no mortar that has commenced to set is remixed. When machine-made lime mortar or any of the hard plasters that are sold already mixed with sand and fiber are specified the care of superintendence is greatly lessened. If improved plasters are used in freezing weather the temperature of the building must be kept above the freezing point until the plaster has set.

CHAPTER XIII.

Specifications.

679. GENERAL CONSIDERATIONS.—The specifications for any particular piece of work should be considered as of equal importance with the drawings. The architect should not expect the contractor to do anything not provided for by the plans and specifications without extra compensation, nor to do the work better than the specifications call for. He must therefore be sure that everything which he wishes done is clearly indicated either by the plans or specifications, and that no loopholes are allowed for poor workmanship or inferior materials. The portions of the work to be done by each contractor should also be clearly stated, so that there can be no misunderstanding as to which contractor is to do certain portions of the work. It very often happens that some minor details, such as the closing up of the windows, the protection of stonework, etc., are not properly specified, and the contractors dispute, much to the annoyance of the architect, as to which one shall do that part of the work. Such annoyances are largely avoided when the entire contract for the erection and completion of the building is given to one person or firm; but even then it is better to have the duties of the subcontractors clearly defined.

As a rule, the form, dimensions and quantity of all materials should be fully indicated on the drawings, so that only the kind and quality of the materials and the manner of doing the work need be given in the specifications. General clauses should be avoided as far as possible, as they only cumber the specifications and tend to obscure the really important portions.

The following forms of specifications for various kinds of mason-work are given merely as guides or reminders for architects, and not as models always to be copied literally. Figures or words enclosed in parentheses, ( ), may be changed to suit special or local conditions.

Every specification should be prepared with special reference to the particular building for which it is intended.

The use of standard specifications is not recommended, because when such specifications are adopted the architect is more apt to overlook important details; and the use of such forms, moreover, tends to prevent progressiveness and study of the construction best suited to the varying circumstances of different buildings.

The author would recommend to the young architect that before commencing to write or dictate his specifications he make a skeleton outline, consisting of headings of the different items to be specified, carefully looking over the plans and revising the outline until everything seems to be covered and the headings arranged in their proper sequence. The specifications can then be filled out in the manner indicated in the following articles.

GENERAL CONDITIONS.

680. Every specification should be preceded by the general conditions governing all contractors. These are sometimes printed on a separate sheet and used as a cover for the written specification. In this case they should not be repeated in the latter.

The general conditions used vary more or less, according to the judgment and experience of different architects.

The following form has been used by the author for a number of years with satisfactory results:

GENERAL CONDITIONS.—The contractor is to give his personal superintendence and direction to the work, keeping, also, a competent foreman constantly on the ground. He is to provide all labor, transportation, materials, apparatus, scaffolding and utensils necessary for the complete and substantial execution of everything described, shown or reasonably implied in the drawings and specifications.

All materials and workmanship are to be of the best quality throughout.

The contractor is to carefully lay out his work and be responsible for any mistakes he may make and any injury to others resulting from them.

Where no figures or memoranda are given the drawings are to be accurately followed according to their scale; but figures or memoranda are to be preferred to the scale measurements in all cases of difference.

In any and all cases of discrepancy in figures the matter is to be

immediately submitted to the architect for his decision, and without such decision said discrepancy is not to be adjusted by the contractor save and only at his own risk; and in the settlement of any complications arising from such adjustment, the contractor is to bear all the extra expenses involved.

The plans and these specifications are to be considered co-operative; and all works necessary to the completion of the design, drawn on plans, and not described herein, and all works described herein and not drawn on plans, are to be considered a portion of the contract, and must be executed in a thorough manner, with the best of materials, the same as if fully specified.

The architect will supply full-size drawings of all details, and any work constructed without such drawings, or not in accordance with them, is to be taken down and replaced at the contractor's expense.

Any material delivered or work erected not in accordance with the plans and these specifications is to be removed at the contractor's expense and replaced with other material or work, satisfactory to the architect, at any time during the progress of the work. Or in case the nature of the defects is such that it is not expedient to have them corrected, the architect shall have the right to deduct such sums of money as he considers a proper equivalent for the difference between the value of the materials or work furnished or executed and the value of the materials or work specified, or a proper equivalent for the damage to the building, from the amount due the contractor on the final settlement of the accounts.

The contractor is to provide proper and sufficient safeguards against and protection from any accidents, injuries, damages or hurt to any person or property during the progress of the work; and he alone is to be responsible, and not the owner or the architect, who is not to be answerable in any manner for any loss or damage that may happen to the work, or to any part thereof, or for any of the materials or tools used and employed in finishing and completing the work.

The contractor is to produce, when called upon by the architect, vouchers from the subcontractors to show that the work is being paid for as it proceeds.

All facilities, such as ladders, scaffolding and gangways, are to be afforded the architect for inspecting the building in safety, and pro-

vision is to be made to the architect's satisfaction for protection from falling materials.

The drawings are the property of the architect and must be returned to him before the final payment is made.

The contractor is to keep the building at all times free from rubbish of all kinds, and on the completion of the work of the contract is to remove all rubbish and waste material caused by any operations under his charge, clean out the building and grounds and leave the work perfect in every respect.

EXCAVATING AND GRADING.

681. The contractor is to visit the site of the building, examine for himself the condition of the lot and satisfy himself as to the nature of the soil.

[Where this is not practicable the architect should show the present grade of lot by red lines on the elevation drawings, and the nature of the soils should be determined by borings or test-pits. See Article 5.]

Loam.—This contractor is to remove the present top soil to the depth of 12 inches from the site of the building and to a distance of (20) feet on each side, and stack it on the lot where indicated.

Excavations are to be made to the depth shown by the drawings for the cellar, areas, coal vault and outside entrance, and for trenches under all walls and piers. All trenches are to be excavated to the neat size as far as practicable, and each is to be levelled to a line on the bottom, ready to receive the foundations. This contractor must be careful not to excavate the trenches below the depth shown by the drawings; should he do so he is to pay the mason for the extra masonwork thereby made necessary, as under no condition will dirt filling be allowed.

All excavations are to be kept at least (12) inches outside the outer face of walls. (See Article 35.)

[Excavations for drains, dry wells, furnace-pit, air-ducts, etc., are to be specified here if required.]

Water.—If water is encountered in making the excavations, this contractor is to keep it pumped out of the way until the footings are set, unless it is practicable to drain it into the sewer.

Rock.—If a solid ledge of rock is encountered in the excavations, this contractor is to remove the same by blasting or other process,

and is to pile the stone on the lot where directed (if it is suitable for the foundation work). For removing such rock an extra sum of (——— cents) per cubic foot of rock excavation is to be paid, but no extra payment is to be made for removing boulders or loose stones.

All material, except the loam and such material as may be needed for filling in about the walls (or for grading), is to be removed from the premises as soon as excavated.

Filling In.—When directed by the architect, this contractor is to fill in about the walls (with stone, gravel or sand) to within (3) feet (half their height) of the finished grade; and as soon as the first floor joists are set he is to complete the filling to the grade line, tamping the earth solidly every 6 inches. (See Article 125.)

Grading.—The surface of the lot is to be graded to the level indicated by the drawings (using the loam first removed) and it is to be left in good condition for top dressing (or for paving). (Foundations for walks and driveways.)

[When building on a site formerly occupied by another structure, or covered with rubbish, the specifications should provide for the removal of all rubbish, débris, old foundation stone, sidewalk stone and other materials that cannot be used in the new building.]

WOODEN PILING.

682. This contractor is to furnish and drive the piles indicated on sheet (1).

All wooden piles are to be of sound (white oak, yellow pine, Norway pine or spruce). They are to be at least (6) inches in diameter at the smaller end and (10) inches in diameter at the butt when sawn off, and are to be perfectly straight and trimmed close and are to have the bark stripped off before they are driven.*

The piles are to be driven into hard bottom or until they do not move more than ½ an inch under the blow of a hammer weighing (2,000) pounds, falling (25) feet at the last blow. They are to be driven vertically and at the distances apart required by the plans.

They are to be cut off square at the head, and, when necessary to prevent brooming, are to be bound with iron hoops.

All piles, when driven to the required depth, are to be cut off by

* This latter clause is not always inserted.

this contractor, square and horizontally and at the grade indicated on the drawings. (See Articles 40 to 45.)

CONCRETE FOOTINGS.

683. All footings colored (purple) on the foundation plans and sections are to be constructed of concrete furnished and put in place by this contractor.

If the trenches are not excavated to the neat size of the footings, or if the concrete is above the level of cellar floor, this contractor is to set up 2-inch planks supported by stakes or solidly banked with earth to confine the concrete; and these planks are not to be removed until the concrete is (48) hours old.

The concrete is to be composed of first-quality fresh —— cement, clean, sharp sand and clean (granite) broken to a size that will pass through a 2½-inch ring, and thoroughly screened. These ingredients are to be used in the proportion of 1 part of cement, 2 of sand and 4 of stone, and mixed each time by careful measurement, in the following manner: On a tight platform of planks four barrows of sand are to be spread, and upon this two barrows of cement. These two materials are to be thoroughly dry-mixed, and on them are to be thrown eight barrows of broken stone and the whole worked over again; the mixture is to be then worked thoroughly and rapidly with shovels while water is being thrown on from a hose, until every stone is completely covered with mortar. No more water is to be used than is necessary to thoroughly unite the materials. As soon as the concrete is mixed it is to be taken to the trenches, dumped in in layers about 6 inches thick and immediately rammed until the water flushes to the top. Each layer is to be deposited before the preceding one becomes dry, and in each case the top surface is to be well wet before a new layer is put in. The stone footings are not to be put on the concrete until it is two days old. (See Articles 499 to 502.)

[On large and important work the specifications should also provide for testing the cement. (See Articles 498 to 502.) The above quantities are as large as should be used for any one mixing.]

SPECIFICATIONS FOR STONEWORK.

684. FOOTINGS.—*Supported on Wooden Piles.*—The wooden pile cappings are to be of evenly split granite blocks (16) inches thick

from the ——— quarries, and are to be of such sizes that no stone will rest on *more than three* piles. These stones are to be bonded as shown on the special drawings. Each and every stone is to be carefully wedged up with oak wedges on the head of each pile to secure a firm and equal bearing, and piles and cappings are to butt closely together.

Dimension Footings.—The footings under all outside foundation walls are to consist of dimension-stone from the ——— or ——— quarries, of the width shown on the section drawings and (12) inches in thickness. The stones are to have fair top and bottom surfaces and are to be bedded and puddled in cement mortar. No footing stone is to be less than (3) feet long.

Rubble Footings.—The footings under (all other) foundation walls are to be built the width and thickness shown on section drawings, of ——— stone. The stonework is to be heavy rubble and each stone is to be the full thickness of the footing course and at least 2 feet 6 inches long, and there are to be not more than two stones abreast in the width of the wall. There is to be one through stone also, the full width of the footings, every (6) lineal feet. Each stone is to be solidly bedded and puddled in cement mortar, and all chinks between the stones are to be filled up solid with mortar and spalls.

685. FOUNDATION WALLS.—*Block Granite or Limestone.*—The foundation walls colored (blue) on plans are to be built to the height and of the thickness shown on section drawings, of sound, evenly split granite (limestone) blocks averaging (3) feet in length and (18) inches in width; and these stones are to be not less than (12) inches in height. They are to be laid with a good bond in regular courses, as near as can be, and to be bonded with one through stone to every (10) square feet of wall.

The stones are to be laid in cement mortar, as described elsewhere, and all chinks and voids are to be filled with slate or (granite) spalls and mortar; they are to show a good straight face where exposed in the basement and the joints are to be neatly pointed with the trowel. All walls are to be built to a line both inside and outside and all angles are to be plumb. (The inside face of the wall is to be hammer-dressed.) The top of the wall is to be carefully levelled for the superstructure with heavy stones at each corner. Holes are to be left in the walls for drain pipes, gas pipes and water pipes.

Rubble Walls.—The foundation and basement walls colored (gray) on plans are to be built to the height and of the thickness shown on section drawings, of —— stone rubble work. The stones are to be selected, large-size, first-quality stones, laid to the lines on both sides, well fitted together, and with all voids filled up solid with spalls and mortar. Each stone is to be firmly bedded and cushioned into place and all joints are to be filled with mortar. The width of at least one-half of the stones is to be two-thirds that of the wall, and there is to be one through stone to every (10) square feet of wall. The larger part of the stones are to be not less than (2 feet) long, (16 inches) wide and (8 inches) thick. The wall is to be laid in courses about (18 inches) high and levelled off at each course.* (Each stone is to have hammer-dressed beds and joints, and the faces of the stones showing on the inside of the walls are to be coarsely bush-hammered.†) The wall to be built plumb and carefully levelled on top to receive the superstructure.

Cementing the Outside of Walls.—As soon as the walls are completed the contractor is to rake out all loose mortar from the outside joints and to plaster the entire outside of the walls (except where exposed in areas) with Portland cement mortar not less than ½ an inch thick. The mortar and sand are to be mixed in the proportions of 1 to 1. Area walls are to have the joints raked out and pointed with cement mortar, and false joints of red cement mortar are to be run with jointer and straight-edge. The trench is not to be refilled until the wall has been plastered at least twenty-four hours.

Basement Piers.—All piers colored (blue) on the basement plans are to be built of ——— stone, and each stone, in plan, is to be the full size of the cross-section of the pier in which it is used‡ and laid on its natural bed; and the top and bottom surfaces of each stone are to be cut so as to form joints not exceeding ½ an inch in width. All four sides of the piers are to be rough-pointed and all corners pitched off to a line. Each top stone is to be dressed to receive the iron plate resting on each pier and each stone is to be solidly bedded in cement mortar as specified elsewhere.

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* This is unnecessary in ordinary foundations for dwellings.

† Required only in places where a neat and extra strong wall is required. This is expensive work.

‡ Or the stones may be laid in courses varying from 8 to 12 inches in height, the stones every other course being the full size of the cross-section of the pier in plan and the intermediate courses consisting of two stones, each one-half the cross-section of the pier. Each stone is to be laid on its natural bed, etc.

Mortar.—All stone masonry referred to is to be laid in mortar composed of perfectly fresh cement, ——— brand, mixed in the proportion of 1 part of cement to (2) parts of clean, sharp sand. The sand and cement are to be mixed dry in a box, then wet, tempered and immediately used. (See Article 201.) No mortar that has commenced to set is to be used on the work.

686. EXTERIOR STONE WALLS.—*Rubble.*—The exterior walls (in first story) are to be built of rubble stone from the ——— quarries. They are to be laid random, with hammer-dressed joints, and the outside faces are to be so split that no projection exceeds 2 inches. The stones are to be laid on their natural bed, with good vertical bond, and there is to be one through stone to every 10 square feet of wall. All stones showing on the exterior are to be selected from the largest in the pile and as few spalls as possible to be used. Every stone is to be well bedded in mortar, made of 1 part cement and (2) parts clean, sharp sand, and all joints and chinks are to be filled up solid with mortar and spalls. All inside joints are to be smoothly pointed with the trowel as the walls are built. After the walls are built the joints on the outside are to be raked out and filled with cement mortar, and false joints of Portland cement mortar colored red are to be run with jointer and straight-edge, in imitation of broken-ashlar.

Field Rubble.—The exterior wall of the (first story) is to be faced with round field-stones, selected for their color, and any moss or lichens is to be left on. The stones are to be fitted together according to their size and without the use of spalls. The back and sides are to be split with a hammer when necessary to make a bond, and each stone is to have its long axis crosswise of the wall and is to be laid in cement mortar. The walls are to be backed up with split-faced rubble carefully bonded to the facing.

CUT-STONEWORK.

687. GRANITE.—All trimmings colored (blue) on the elevation drawings are to be of ——— granite. The stock is to be carefully selected and to be free from all natural imperfections, such as mineral stains, sap or other discolorations; and it is to be of an even shade of color throughout, so that one stone will not be of a different shade from another when set in place.

The faces of sills, caps, quoins and water-tables, where so indicated on the elevation drawings, are to have a pitched-face finish,

with 1-inch angle margins on quoins and water-tables. The finish of all steps and thresholds is to be hammered work, six-cut, and the balance of the finish of trimmings is to be the best eight-cut work.

Sandstone.—All trimmings colored (brown) on the elevation drawings are to be of best quality selected sandstone, of uniform color and hardness, free from sand holes and rust, and cut so as to lie on its natural bed when set in the wall. All stone trimmings thus shown are to be worked in strict accordance with the detail drawings, with true surfaces and good sharp, straight lines; and all stone belts, unless otherwise provided for, are to have a bearing upon the walls of at least (6) inches, and all projecting courses a bearing of 2 inches more than the projection. All exposed surfaces of the sandstone are to be carefully tooled, (rubbed) or (crandalled), the workmanship being regular and uniform in every part and done in a skilful manner. All moldings are to be carefully fitted together at the joints, and no horizontal or vertical joint is to exceed $\frac{3}{16}$ of an inch. All return heads at the angles, etc., are to be at least (12) inches in length. No patching of any stone is to be allowed.

[Ordinary soft sandstones, or "freestones," are not suitable for steps and door sills, which should be of granite or of some hard sandstone or limestone.]

Ashlar.—The (south) and (west) walls of the building where exposed above the (water-table) are to be faced with coursed-(broken) ashlar of the same stone as specified for the trimmings. The ashlar is to be laid in courses (12) inches in height, except as otherwise shown on elevation drawings, and is to have plumb bond wherever practicable. (The surface of the quoins is to be raised 1 inch from the face of the wall, with bevelled or rusticated joints, and the faces of the stones are to be rusticated in a skilful manner. Each quoin is to be (16) by (24) inches, alternately reversed as shown on the drawings.) The balance of the ashlar is to be rubbed to a true surface, to be out of wind, cut to lie upon its natural bed, and laid up with $\frac{3}{16}$-inch joints. No stone is to be less than 4 inches thick, and at least one jamb stone of each opening is to extend through the wall. All mullions 16 inches or less in width are to be cut the full thickness of the wall.

The contractors, for both the granite and the sandstone, are to do all drilling, lewising, fitting and other jobbing required for setting

the stone or for receiving the iron ties, clamps, etc., and are to provide all patterns necessary and requisite for the execution of the work.

Setting Cut-stonework.—[The specifications should state distinctly who is to set the cut-stonework. If it consists of a few trimmings only it costs less to have the brick-mason set it; but if there is a large quantity of it, it should be set by the stone-mason.]

All cut-stonework colored (blue) or (brown) on the elevation drawings, and previously specified, is to be set by this contractor in the best manner in mortar mixed in the proportions of 2 parts of ——— lime mortar and 1 part of fresh ——— cement. The cement is to be mixed with the lime mortar in small quantities and in no case is any to be used that has stood over night. (For setting limestone and marble see Article 311.)

As the stone is delivered at the building the mason contractor is to receive the same and is to be held responsible therefor until the full completion of his contract; any damage that may occur to any stone, whether on the ground or in the building, during the said period, is to be made good at his own expense and to the satisfaction of the architect or superintendent.

The mason is to call upon the carpenter to box up or otherwise protect by boards all steps, moldings, sills, carving and any other work liable to be injured during the construction of the building.

Every stone is to be carefully set, joints are to be left open under the middle part of sills and at the outer edges of all stonework. All stones are to be uniformly bedded and joints kept level and plumb and of uniform thickness. The mason is to provide derricks and all other apparatus necessary to set the stone properly and is to carry on the work so as not to delay the other mechanics. Where the stone is backed up with brick it is to be set not more than two courses ahead of the brick backing.

Anchors and Clamps.—This contractor is to provide all necessary iron anchors and clamps (which are to be galvanized or dipped in tar) for securing the stones as herein specified or as directed by the superintendent.

Each piece of ashlar 12 inches or more in height is to have one iron anchor extending through the wall, and when exceeding 4 feet in length it is to have two clamps. (Broken ashlar is to be bonded by through stones, one to every 10 square feet of wall.)

All projecting stones, corbels, finials, etc., are to be anchored with iron anchors which are satisfactory to the superintendent. All coping stones and other horizontal string-courses or cornices, where so indicated by notes on the drawings, are to be clamped together.

Cleaning and Pointing.—After all the stonework is set complete (and the roof is on) the mason is to scrub it down with muriatic acid and water, using a stiff bristle brush; and he is to rake out all joints to a depth of 1 inch and repoint them with Portland cement and ——— red mortar color, well driven into the joints and rubbed smooth with the jointer with half-round raised joints, as per marginal sketch. (It is well to show on the margin of the specifications the kind of joints desired; see also Article 313.)

The entire work is to be left clean and perfect on the completion of the contract.

SPECIFICATIONS FOR BRICKWORK.

688. This contractor is to furnish all materials, including water, and all labor, scaffolding and utensils necessary to complete the brickwork indicated by (red) color on the plans and sections and as shown on the elevations and as herein specified.

Pressed Bricks.—The exposed surfaces of the building (on the south and east elevations), including the chimneys, are to be faced with ——— pressed bricks like the sample in the architect's office. All are to have good sharp edges and to be of uniform size and color.

Molded Bricks.—Furnish all molded bricks shown on elevation drawings and as indicated by numbers (which refer to ———'s catalogue). The color of these bricks is to match as closely as possible the color of the pressed bricks, which are to be laid so as to give to all moldings, etc., lines which are as even as possible. Angle bricks are to be furnished for external angles of bays and circular bricks of proper curvature for the circular bays (or towers).

Stock Bricks.—The exposed surfaces of the brickwork (on the west elevation) are to be laid up with best quality dark red stock bricks, with good sharp corners and square edges.

Common Bricks.—The balance of the exposed brickwork is to be constructed of selected, even-colored common bricks carefully culled and as nearly uniform in size and color as can be obtained.

All face bricks are to be laid in the most skilful manner (from outside scaffolds) in colored mortar, as specified elsewhere.

Each brick is to be dipped in water before it is laid; the bricks are to be butted and all vertical joints filled solid from front to back. The bricks are to be laid with plumb bond and bonded to the backing with one diagonal header to every brick in every (fifth) course. [Or bonded with the ——— ties, one tie being laid over every brick in every (fourth) course.] In piers only solid headers are to be used.

All courses are to be gauged true and all joints rodded (or struck with a bead jointer. See Article 342).

The returns of pressed brickwork are to be carefully dovetailed into the common brickwork or bonded by solid headers.

Ornamental Work.—All brick cornices, belt-courses, arches, chimney tops and other ornamental brick features of the building are to be laid up in the most artistic and substantial manner, according to the scale and detail drawings. All arches are to be bonded and the bricks cut and rubbed so that each joint radiates from the center. (Arch bricks are often specified for first-class work in large cities.)

Common Brickwork.—All other brickwork is to be laid up with good hard-burned (the best merchantable) common bricks, acceptable to the architect, and in mortar as specified elsewhere.

All bricks are to be well wet, except in freezing weather, before being laid.

Each brick is to be laid with a shoved joint in a full bed of mortar, all interstices being thoroughly filled, and where a brick is laid in connection with anchors it is in every case to be "brought home" to do all the work possible.

Up to and including the fourth story every fourth course is to consist of a heading course of whole bricks, extending through the entire thickness of the wall or backing; above the fourth story every sixth course is to be a heading course.

All mortar joints, in walls which are not to be plastered, are to be neatly struck, in the manner customary in first-class trowel work. All courses of brickwork are to be kept level and the bonds accurately preserved. When necessary to bring any courses to the required height, clipped courses are to be formed (or the bricks laid on edge), as in no case are any mortar joints to finish more than ½ an inch thick. All brickwork is to be laid to the lines, and

all walls and piers built plumb, true and square. Walls are to be carefully levelled for floor joists.

All cut-stone is to be backed up as fast as the superintendent directs, and the brick-mason is to build in all anchors that are furnished by the contractor for the cut-stonework, by the contractor for the carpentry work or by the contractor for the ironwork.

All partition walls are to be tied to the outside walls by iron anchors (furnished by this contractor), $\frac{3}{16}$ by $1\frac{3}{4}$ inches in cross-section and (3 feet 6 inches) in length, built into the walls every (4) feet in height.

When openings or slots are indicated in the brick walls the size and position of the same are to be such as the superintendent directs, unless otherwise shown. This contractor is to leave openings to receive all registers that may be required in connection with the heating or ventilating system.

The work is to be firmly bedded and filled in around all timbers, pointing is to be done around all window frames, inside all staff-beads and window sills and wherever required, and all wall-plates are to be bedded in mortar on the brickwork.

Protection.—This contractor is to carefully protect his work by all necessary bracing and by covering up all walls at night or in bad weather. He is to protect all masonwork from frosts by covering it with manure or other materials satisfactory to the superintendent.

The top portions of all walls injured by the weather are to be taken down by this contractor at his expense before recommencing the work.

Hollow Fire-clay Bricks (for buildings of skeleton construction). —All bricks used in connection with the spandrels above the first story on all elevations, together with all backing required in connection with the stone or terra-cotta work above the (sixth) story floor beams, are to consist of first-quality hard-burned fire-clay, hollow bricks, equal in quality to the sample in the architect's office. Each brick is to be laid with a shoved joint and the work is to be well bonded. The inside surfaces of the walls are to be left smooth, true and ready for plastering.

Cement Mortar.—All brickwork below the grade line and the last five courses of all chimneys and parapet walls are to be laid in mortar composed of 1 part fresh cement and (2) parts clean, sharp

bank sand, properly screened, and mixed with sufficient water to give the mixture proper consistency. Care is to be taken to thoroughly dry-mix the sand and cement in the proportions specified before adding the water. The mortar is to be mixed in small quantities only, and in no case is mortar that has commenced to set or that has stood over night to be used. (See Articles 201 to 205.)

[In Colorado, and possibly in some other localities, a gray hydraulic lime is obtained, which answers about as well as cement for mortar for foundation walls.]

Lime-and-cement Mortar.—All common brickwork in (first and second) stories is to be laid in mortar composed of (3) parts of lime mortar, having a large proportion of sand and of 1 part of fresh ——— cement. The lime mortar is to be worked at least two days before the cement is added, and only small quantities of cement are to be mixed at a time. (See Article 201.)

Lime Mortar.—The balance of the common brickwork is to be laid in mortar composed of fresh-burned ——— lime and clean, sharp sand, well screened. (No loam is to be used.) The lime and sand are to be mixed in proportions which make a rich mortar, satisfactory to the architect. Lime that has commenced to slake is not to be used.

Colored Mortar.—All face-bricks are to be laid in mortar composed of lime putty and finely sifted sand, colored with ——— or ——— mortar stains; the colors are to be selected by the architect.

Grouting.—All brick footings and the piers in the basement are to be grouted in every course and flushed full with cement mortar as specified above.

Cement Plastering.—The outside surfaces of all brick walls that come in contact with the earth are to be plastered smooth by this contractor, from bottom of footings to grade line, with ——— Portland cement mortar, mixed in the proportion of 1 to 2, and put on to an average thickness of ½ an inch.

The top surfaces of all projecting brick belt-courses, and the tops of fire-walls, where not otherwise protected, are to be plastered with the same kind of mortar, care being taken to make a neat job. (See Article 346.)

Relieving-arches.—Three rowlock relieving-arches are to be turned over all door and window openings behind the face-arch

or lintel. These arches are to have brick cores, and are to spring from beyond the ends of the wood lintels.

Chimneys.—All chimneys and vent-flues are to be built as shown on plans, sections and scale drawings, and topped out as shown on elevation drawings.

All withes are to be 4 inches thick and well bonded to the walls, and the flues are to be carried up separately to the top. The inside of all flues (unless provided with flue linings) are to be plastered from bottom to top with (Portland cement) mortar, and the outside surfaces are to be plastered where the flues pass through floors. [The plastering of the inside of smoke flues is not allowed in some building ordinances.]

Slides (slanting boards) are to be put in each flue at the bottom, with openings above to take out the mortar droppings; and on completion of the chimneys the flues are to be thoroughly cleaned out and the openings bricked up.

All brick chimney-breasts are to be built plumb, straight and true, and all corners are to be square.

Rough openings are to be built for fireplaces (with ½ by 2-inch iron arch-bars, turned up 2 inches at the ends) and trimmer arches are to be built for the same, 2 feet wide, on wooden centers, furnished and set by the carpenter.

Ash-pits are to be built under grates, as shown on plans, and a cast-iron ash-pit door and frame are to be provided and set in each pit where shown or directed.

Flue Linings.—Fire-clay flue linings, 8 by 12 inches in size, are to be furnished and set in (the range flues and furnace flues) and are to start (2 feet) below the thimble and to be continued to the top of each flue. The lining is to be set in rich lime (cement) mortar, with joints scraped clean on the inside.

Thimbles.—The contractor is to provide and place in all flues, except grate flues, (sheet) iron thimbles, 8 inches in diameter in the furnace flue and 6 inches in diameter elsewhere, and set 2 feet below the ceiling unless otherwise directed. He is to furnish bright-tin stoppers for all thimbles except for (range and furnace).

Cold-air Duct.—Contractor is to excavate for and build the cold-air duct and foundation for furnace, as shown on drawings, of hard-burned bricks, laid in ——— cement mortar, and plastered smooth on the inside; he is also to plaster the bottom of duct and

furnace pit with cement mortar on a 2-inch bed of sand. The top of the air duct is to be covered with (2½)-inch flagstones, with joints neatly fitted and edges cut true and square. The flagging is to be furnished by (this) contractor.

Fire-walls.—This contractor is to furnish and set, in Portland cement, salt-glazed tile copings on all fire-walls not covered by stone or metal copings. The copings are to be 2 inches wider than the walls and are to have lapped joints.

Ventilators.—Ventilating openings are to be left in the foundation walls and between the roof and ceiling joists, where shown on drawings, and cast-iron gratings are to be placed in the openings.

Cutting and Fitting.—This contractor is to do promptly and at the time the superintendent directs all cutting and fitting required in connection with the masonwork by other contractors in order that their work may be properly installed, and he is to "make good" after them.

Setting Ironwork.—This contractor is to set all iron plates resting on the brickwork, and all steel beams supporting brick walls; also all iron lintels, tie-rods and skewbacks used in connection with brick arches or over openings.

All such work is to be delivered at the sidewalk by another contractor, and this contractor is to set the same in such position and at such height as the superintendent shall direct. All plates are to be solidly bedded, true and level, in 1 to 2 fresh ——— Portland cement mortar; the brickwork is to be brought to such a height that the bedding joint shall not exceed ½ an inch in thickness.

[Where there is but little ironwork it is sometimes desirable to specify that the brick-mason shall assist the carpenter in setting iron columns and steel beams. Large contracts for iron and steel work are generally carried out by a special contractor. All ironwork coming in connection with the stonework should be set by the same contractor that sets the stonework.]

Setting Cut-stone.—The contractor for the stonework is to set all belt-courses, stone arches, copings, steps and other stones where fitting is required; but this contractor is to set all single caps, sills and bond-stones, the stones being delivered at the sidewalk. All such pieces of stone are to be set in the best manner, in mortar as specified for the face-bricks. Sills are to be bedded at the ends only.

Setting Terra-cotta.—This contractor is to set all terra-cotta work colored (pink) on the elevation drawings in the best manner and in the same kind of mortar as is specified for the pressed brickwork. All terra-cotta work that does not balance on the wall, and any other terra-cotta work, if so indicated on the drawings, is to be securely tied to the backing by wrought-iron anchors of approved pattern, thoroughly bedded in cement mortar. (See also "Specifications for Terra-cotta Work.")

Cleaning Down and Pointing.—On the completion of the brickwork this contractor is to thoroughly clean the face-brick, using dilute muriatic acid and water, applied with a scrubbing brush. Care is to be taken not to let the acid run over the cut-stone. (Some stones are injured by acid and must be cleaned with water only.) While cleaning down, this contractor is to point up under all sills and wherever required, in order to leave the walls in perfect condition.

[Where there is little cut-stonework the cleaning and pointing of it may also be included in this specification.]

Outhouses. [Generally customary only in Western cities.]—The outhouses and ash-pit are to be built of hard-burned bricks on the rear of the lot where shown on plans. The ash-pit is to be arched over and given a heavy coat of (Portland) cement mortar. An opening is to be left in the top for putting in ashes and an iron ring and cover provided for the opening. On the alley side at the grade a cast-iron ash-pit door and frame are to be furnished and set.

Rubbish.—This contractor is to clean out all boards, planks, mortar, bricks and other rubbish caused by the brick-masons, and to remove such rubbish from the building and grounds, on completion of the brickwork or when directed by the superintendent.*

Brick Paving (for yards).—The yards and areas, where so indicated on plans, are to be paved with good hard (vitrified) paving bricks, sound and square, laid flat, herringbone fashion, on a bed of sand from (4) to (6) inches deep.

[The necessary depth of sand varies with the quality of the soil, a stiff clay requiring the most sand; on such soils a bed of furnace cinders, etc., may be used to advantage before the sand is put down.]

After the bricks are laid and placed with the proper grade (which

* If in the general conditions this paragraph may be omitted here.

should be about 1 inch in 10 feet), to drain the water to the grade or to its proper outlet, the entire surface is to be covered with sand, which is to be swept over the bricks until the joints are thoroughly filled.

[For a better pavement the joints should be grouted in liquid cement mortar and the sand spread over afterward. Where an extra thickness of wearing surface is required the bricks may be laid on edge and grouted or covered with sand as above.]

Where brick gutters are shown the bricks are to be laid lengthwise and the joints grouted in cement mortar.

(For the requirements for paving-bricks for streets and driveways see Article 331.)

SPECIFICATIONS FOR LAYING MASONRY IN FREEZING WEATHER.*

689. Only in case of absolute necessity is any masonry to be laid in freezing weather. (See Articles 213, 214 and 344.)

Any masonry laid in freezing weather is not to be pointed until the warm weather in the spring. If necessary, masonry may be laid in freezing weather, provided the stones or bricks are warmed sufficiently to remove ice from the surface and the mortar is mixed with brine made as follows: One pound of salt is to be dissolved in 18 gallons of water when the temperature is at 32° Fahr., and 1 ounce of salt is to be added for every degree the temperature is below 30° Fahr., or enough salt, whatever the temperature, to prevent the mortar from freezing.

SPECIFICATIONS FOR FIRE-PROOFING.†‡

(HOLLOW TILE SYSTEM.)

690. The following specifications are intended to include the fire-proofing of all the steel in the building, the filling in between the beams forming the floors and the roof and the concreting over the same to the top of the floor strips. They include, also, the covering of all columns, both those standing clear and those partly incased in the walls, the building of all tile partitions and tile vaults and the walls of pent-houses on the roof.

* "Treatise on Masonry Construction." Ira O. Baker.

† Modelled after the specification for the Fort Dearborn building, Chicago, Ill.; Messrs. Jenny & Mundie, architects.

‡ On account of various changes in the methods and details of this branch of building construction this form for the specifications for fire-proofing must be used in the light of the revised data and statements given in Chapter IX on "Fire-proofing of Buildings."

This contractor is to furnish all materials, including the mortar for setting the same, and is to do all his own hoisting and set all the work in a thorough, substantial and workmanlike manner, to the satisfaction of the superintendent.

Mortar.—All work is to be laid in mortar composed of 3 parts of best fresh lime mortar and 1 part of ——— cement, thoroughly mixed together just before using. Said lime mortar is to be composed of fresh-burned lime and clean, sharp sand in proportions best suited to this work.

Floors.—All floors are to be constructed of flat arches (of porous or semi-porous tiles, end-method construction*) set in between the beams and of a shape that will give a uniform flat ceiling in the rooms below. The bottoms and projections of all beams and girders are to be protected by projecting parts of the tiles or by separate beam slabs. In laying the floor arches every floor joint is to be filled full over its entire surface from top to bottom. No joints are to exceed $\frac{3}{16}$ of an inch in thickness.

No clipped or broken tiles are to be used in the arches, and there is to be no cutting of arches except where absolutely necessary or with the approval of the superintendent. All the arches are to be formed to fit the various spans between floor beams, and in all cases special patterns of voussoirs or keys are to be molded and set where it is impossible to set the regular forms.

All floor arches, ten days after they are laid, and before they are concreted, are to be subject to a test of a roller, 15 inches face, and loaded so as to weigh 1,500 pounds, rolled over them in any direction.

[This test is only intended to provide against poor workmanship and improper setting of the tiles. If any system whose strength has not been fully demonstrated is to be used it should be subjected to a severer test.]

Columns.—All columns are to be covered with (porous) column tiles held by metal clamps, both in the horizontal and vertical joints. These column protections are to be so made as to conform with the city ordinances. (See Articles 416 and 417.)

[Where the city ordinances are not sufficiently strict on this point the specifications should be more definite as to the shape of the tiles.]

* This clause is not in the Fort Dearborn specification.

Roofs.—The roofs are to be constructed in the same way as the floors, except that the tops of the tiles are to be flush with the beams and that the soffits may be segmental, with raised skewbacks. (See Article 463.)

Partitions.—This contractor is to build all partitions shown on the several plans of (porous, semi-porous or dense) hollow tiles, 4 inches thick in the first and second stories and 3 inches thick in all other stories, except the hall partitions, which he is to build 4 inches thick throughout the building.

In glazed partitions the lower parts and all parts other than the sashes and frames are to be of tile.

The tiles are to be set breaking joints and are to be tied with metal ties or clamps. (See Articles 466 and 471.)

Furring for False Beams and Cornices.—This contractor is also to furnish and put in place the tile furring for the cornices and false beams in the (bank and assembly-hall). The profiles and sections are to be as shown on the drawings. (See Articles 484 and 487.)

The coves and ceiling pieces of the cornice and all parts of the beams are to have holes cast for bolts, spaced not over 12 inches apart and for at least two bolts for each piece. The furring is to be properly and securely mitered at angles and all is to be properly bedded, with close joints, in mortar as specified above.

All suspended pieces are to be substantially fastened in place with ¼-inch diameter T-head bolts, spaced not over 12 inches apart, with nuts and washers to each.

(Or, all furring for cornices and false beams are to be put up by the contractor for plastering.)

Wall Furring.—The outside walls in the finished portions of the basement are to be furred with 3-inch (porous, semi-porous or dense) tiles, so as to form vertical and true surfaces for plastering or tiling. The tiles are to be set with the hollow spaces vertical, and are to be securely fastened to the walls by flat-headed spikes. (See Articles 484 and 485.)

Miscellaneous.—All tilework is to be straight and true.

All tiles of every kind are to be thoroughly burned and free from serious cracks, checks or other damages, and are to be laid in a proper and workmanlike manner.

No centers are to be lowered until the mortar has set hard.

All structural steel on which the strength of the building depends in any way, including the wind-bracing, is to be protected by fire-proof covering of approved shape substantially fixed in place.

All tilework is to be left in suitable condition for plastering.

Concreting.—This contractor is to fill in on top of the floor arches with concrete composed of 1 part of ——— cement mortar and 4 parts of screened boiler cinders, levelled off at the top of the highest beams or girders; and after the floor strips are set by the carpenter the contractor is to fill in between said strips with the same concrete pressed down hard with a reasonably true surface 1/8 of an inch below the top of the strips.

All damage to tilework is to be repaired before the concrete is laid. (See Article 412.)

Roofs.—This contractor is to cover the surface of the roof tiles with 1 to 3 ——— cement mortar of sufficient thickness to come 3/4 of an inch above the top flanges of beams and girders, and is to give the required pitch to the roof, with a reasonably uniform surface. (See Articles 463 and 464.)

[If the tops of the tiles are more than 3/4 of an inch below the tops of the girders, concrete may be used for filling in to the top of the girders and 3/4 inch of mortar for applying above.]

Pent-house.—The outside walls of the pent-house on roof are to be built of (4-inch) hard-burned wall tiles, clamped together, and set in mortar as above specified. Every joint, both vertical and horizontal, is to be thoroughly filled over its entire surface with mortar, and all outside joints are to be struck in a neat and workmanlike manner.

This contractor is to give a written guarantee that the outside face of these tiles will stand the weather for (five) years, dating from the completion of the walls, and is to agree to replace any tiles injured by the weather, either in winter or summer, during said period, promptly and at his own expense.

SPECIFICATIONS FOR TERRA-COTTA TRIMMINGS.*

691. MATERIALS.—This contractor is to furnish and set, wherever called for on the drawings, terra-cotta to exactly match in color the sample submitted, all in strict accordance with the detail

* From specifications of Fort Dearborn building.

drawings. Material for all terra-cotta is to be carefully selected clay, left in perfect condition after burning, and uniform in color. All pieces are to be perfectly straight and true, and with mold of uniform size where continuous. No warped or discolored pieces will be allowed. This contractor is to furnish a sufficient number of extra pieces, so as to avoid all delay.

Modelling.—All work is to be carefully modelled by skilled workmen, in strict accordance with the detail drawings, and models are to be submitted for the architect's approval before the work is burned. No work burned without such approval will be accepted by the architects unless perfectly satisfactory.

Mortar.—All mortar used for exposed joints in terra-cotta work is to be composed of lime putty, colored with ——— mortar stains to match the mortar used for pressed brickwork.

Ornamental Fronts, Belt-courses, Bands.—This contractor is to furnish and set all ornamental terra-cotta, belt-courses and bands, as shown on elevations or sections or where otherwise indicated, in strict accordance with detail drawings. All terra-cotta work is to be secured to the ironwork in the most approved manner, with substantial wrought-iron or copper anchors, and thoroughly bedded in cement mortar. All horizontal joints are to have lap joints. All projecting courses are to have drips formed on the under side.

Caps, Jambs and Sills.—All caps and jambs where indicated as terra-cotta are to be constructed in strict accordance with the detail drawings. All sills and belt-courses are to have countersunk cement joints as directed by the superintendent. All projecting sills are to have drips formed on the under side and all sills are to be raggled for hoop-iron, which is to be bedded by this contractor in cement mortar.

Terra-cotta Mullions.—All ornamental mullions of terra-cotta are to be secured to metal uprights in an approved manner, and are to be well bedded and slushed with cement mortar.

Cornices.—This contractor is to construct the cornices in strict accordance with the detail drawings, with sufficient projection through walls and approved anchorage to the metalwork to make them thoroughly secure. This contractor is to furnish all necessary anchors. He is to form raggle in cornices as shown for connection of gutters; and this raggle is to be on the face of the terra-cotta. He is to leave openings in the cornices for down-spouts as shown.

Anchors.—This contractor is to furnish all anchors substantially made of wrought-iron or copper for the proper support and anchoring of all terra-cotta used in his work. All terra-cotta is to be drawn to tight and accurate joints to the entire satisfaction of the superintendent. All terra-cotta is to fit the supporting metalwork exactly.

Cutting and Fitting.—This contractor is to do all fitting necessary to make his work perfect in every particular, and all possible cutting and fitting are to be done at the factory before delivery.

Protection of Terra-cotta.—All projecting terra-cotta is to be protected with sound planks during the erection of the building by the terra-cotta contractor, and said protective pieces are to be removed when the building is cleaned down.

Cleaning Down.—This contractor is to carefully clean down all terra-cotta work on the completion of the building, when directed by the superintendent, and he is to carefully point up all joints before leaving the work.

SPECIFICATIONS FOR LATHING AND PLASTERING.

(ORDINARY WORK.)

692. LATHING.—All (walls) partitions and ceilings, and all furring, studding, under sides of stairs, etc., are to be lathed with best quality pine (spruce) laths, free from sap, bark or dead knots, and of full thickness. They are to be laid ⅜ of an inch apart on the ceilings and ¼ of an inch or more apart on the walls, with four (five) nailings to a lath and with joints broken every 18 inches; all are to be put on horizontally. Under no circumstances are laths to stop and form long, straight vertical joints, nor are any laths to be put on vertically to finish out to angles or corners. No laths are to run through angles and behind studding from one room to another. All corners are to be made solid before lathing. Should the lathers find any angles which have not been made solid, or any furring or studding which has not been properly secured, they are to stop and notify the carpenter to make the same solid and secure.

Metal Lathing.—Walls or partitions in front of hot-air pipes are to be lathed with metal lathing approved by the architect. All recesses in brick walls that are to be plastered, all wood lintels and all places where woodwork joins brick walls (if the latter are not

furred) are to be covered with ———, or expanded-metal lathing properly put up and secured.

PLASTERING. *Back-plastering* (for frame buildings).—This contractor is to back-plaster the entire surface of the exterior walls between the studs from sills to plates, and also between the rafters of the finished portions of the attic, on laths nailed horizontally, ⅜ of an inch apart, to other laths or vertical strips put on the inside of the boarding, with one heavy coat of lime-and-hair mortar, well trowelled and made tight against the studs, girts, plates and rafters.

One-coat Work.—The (basement ceiling) is to be plastered one heavy coat of rich lime-and-hair mortar, well trowelled and smoothed.

Three-coat Work.—All other walls, partitions, ceilings and soffits throughout the building are to be plastered three coats in the best manner.

The first or scratch coat is to be made of first quality ——— lump lime, clean, sharp bank (river) sand, free from loam and salt, and best quality clean, long cattle hair, mixed in the proportion of 5⅓ barrels of sand and 1½ bushels of hair to each cask or each 200 pounds of lump lime. All are to be thoroughly mixed by continued working and stacked in the rough for at least (7) days before putting on. The hair and sand are not to be mixed with the lime until the lime has been slaked at least six hours.

The scratch coat is to be properly put on and applied with sufficient force to give a good clinch, and is to be well scratched and allowed to dry before the brown coat is put on.

The second or brown coat is to be mixed in the same manner as the scratch coat (except that 6½ barrels of sand and but ½ a bushel of hair to 1 of lime may be used). The contractor is to level and float up the brown coat and make it true at all points.

White Coat.—The third coat (except in the halls and dining-room) is to be mixed with lime putty, plaster of Paris and marble dust [or lime putty and ——— hard wall plaster], thoroughly trowelled and brushed to a hard, smooth surface.

Sand Finish.—The third coat in the halls and dining-room is to be composed of lime putty and clean-washed (beach) sand, floated with a wooden or cork-faced float to an even surface, with a texture corresponding to that of No. 1 sandpaper.

All lathing and plastering are to extend clear down to the floor;

all walls are to be straight and plumb and even with the grounds; and all angles are to be maintained sharp and regular in form.

Plaster Cornices, etc.—The contractor is to run around the (parlor) a plaster stucco cornice, to extend (8) inches on the ceilings and (6) inches on the walls, and to be in strict accordance with the detail drawings. All beads, quirks, etc., are to be run to the angles of beam soffits as indicated on the drawings, and a finish is to be made at each end of the beams with cast plaster brackets, modelled according to the architect's full-size details.

The contractor is to put up cast plaster centerpieces in (3) rooms, for which he is to allow the sum of ($25). The same is to be expended under the direction of the architect.

The plasterer is to clear out all boards, planks, horses, mortar, dirt and all loose rubbish made by him or his men, and remove such materials and rubbish from the rooms and premises as fast as the several stories are plastered, and leave the floors broom-clean. He is to *patch up* and repair the plastering after the carpenters and other mechanics in a skilful manner and leave the work perfect on completion.

Two-coat Work. New England Practice.—The following is the usual form of specification for housework in New England:

All walls, ceilings, soffits and partitions throughout the (first and second stories and attic) are to be plastered two coats in the very best manner.

"The first coat is to be of best quality (Rockland) lime and clean, sharp sand, well mixed with 1½ bushels of best long cattle hair to each cask of lime; these materials are to be thoroughly worked and stacked at least one week before using, in some sheltered place, but not in the cellar of the house; all the work is to be well trowelled, straightened with a straight-edge, made perfectly true and brought well up to the grounds.

"The second or 'skim' coat is to be of best (Rockland) lime putty and washed (beach) sand, trowelled to a hard, smooth surface."

SPECIFICATIONS FOR HARD PLASTERING.

693. All walls, ceilings, soffits and partitions throughout the building are to be plastered three coats, in the best manner, as specified on opposite page.

The first and second coats are to be of ——— wall plaster or dry mortar and the first coat on the lathwork is to be fibered material.

The material is to be mixed with clean water to the proper consistency and applied in the usual way. The first coat is to be scratched or broomed to form a rough surface for the brown coat. The brown coat is to be applied as soon as the scratch coat is two-thirds dry or has set sufficiently to receive it, and the mortar is to be brought out even with the grounds and to a true surface. The work is to be scratched roughly for all stucco cornices and moldings.

Sand Finish.—After the brown coat has been on twenty-four hours the plasterer is to finish the walls and ceilings of (halls and vestibules) with ——— sand finish, mixed with clean water only and floated to a true surface with clear soft pine or cork-faced floats.

[Or lime putty and sand may be used as in ordinary plastering.]

Hard Finish.—When the browning is two-thirds dry the plasterer is to finish all other walls and ceilings throughout the building with a white coat made of equal parts of lime putty and plaster of Paris, trowelled and brushed to a hard and uniform surface.

[For a better grade of finish a quart of marble dust is to be added to each batch of plaster, or ——— hard wall finish is to be used instead of plaster of Paris.]

All brick and tile walls and all wooden laths are to be well wet just before plastering.

Only as much mortar as can be used within one hour is to be mixed at one time, and under no circumstances is any mortar that has commenced to set to be retempered.

The plasterer is to strictly observe and follow the directions accompanying the plaster.

[Specify for patching, cornices, etc., as in Article 692.]

SPECIFICATIONS FOR WIRE LATHING WITH METAL FURRING.

(OVER WOODWORK.)

694. This contractor is to fur all ceilings, soffits of stairs, all timber beams and posts, and both sides of all wood partitions throughout the building with ——— metal furring, and a line

of furring is to be placed on each side of each angle, as near the angle as possible. Posts and girders are to be furred lengthwise, with a line on each angle, and every ( ) inches between.

[If the architect does not wish to specify any particular or patent kind of furring he can specify 3/32 by ⅞-inch corrugated band-iron, put up with 1¾-inch staples.]

All furring is to be substantially secured with ( ) and to be set to give a true and even surface for the lathing.

This contractor is to cover all the above surfaces with (plain, painted, japanned, galvanized) wire lathing (2½ by 2½) (2½ by 4) mesh, No. (20) wire, tightly stretched and secured with (2)-inch No. 13 steel staples driven over the lath and furring at each bearing where the lathing runs crosswise of the timbers, and every (6) inches where the bearings run parallel with the timbers. The lathing is to be lapped at least ½ an inch where the strips come together and 1½ or 2 inches at all angles of walls or of walls and ceilings.

SPECIFICATIONS FOR STIFFENED WIRE LATHING.

(OVER WOODWORK AND BRICKWORK.)

695. This contractor is to cover all ceilings, soffits of stairs, both sides of all wood partitions, and all wooden posts and girders throughout the building with the ——— stiffened wire lath, painted, No. 20 gauge, and (2½ by 2½) (2½ by 4) mesh, with (½-inch) V-ribs. [On posts and girders and on planking 1-inch ribs will give better protection from both fire and dry rot.]

The lathing is to be applied with the ribs running at right-angles to the beams; it is to be tightly stretched and secured with galvanized-steel nails, driven through each end of each rib, and at every bearing between; and every 9 inches on timbers and planking. The strips are to lap on a joist in every case and are to be carried down 2 inches on the walls. Care is to be exercised to see that no holes are left at any place in the ceiling where the plastering can drop off and fire enter.

The outside walls of the finished portion of basement, from floor to ceiling, are to be lathed with ——— stiffened lathing, painted, No. 20 gauge, (2½ by 4) mesh and 1-inch V-ribs. The lathing is to be tightly stretched, lapped 1 inch and secured to the walls with

tenpenny steel nails driven through the ribs every 8½ inches and at each end. The lathing is to be applied with the stiffening bars in a vertical position. All this lathing is to be done in the most approved manner, so as to give a firm surface upon which to apply the plaster.

SPECIFICATIONS FOR METAL LATH ON IRON-WORK.

696. This contractor is to furnish and put up in a substantial manner all iron furring and lathing for enclosing the posts and girders and for forming the cornices, as shown on the drawings and as specified below. The lathing is to be well lapped over on the walls and ceilings to make a tight job.

Girders.—All girders projecting below the level of ceilings are to be encased with wire lathing, stiffened with ¼-inch solid ribs. The lathing is to be rightly supported by light iron furring built out to the correct outline as shown on the plans. The furring is to be so designed that the weight of the plaster and falsework will be supported by the girders and firm surfaces afforded for plastering.

Cornices.—Full-size details of all cornicework is to be supplied by the architects at the proper time. Iron brackets, bent to correct outlines and spaced not more than 18 inches apart, are to be secured in position in the best manner and well braced. Over this false-work, wire lathing, stiffened with ¼-inch steel ribs, is to be laced so as to conform with the profiles of the brackets and produce smooth, firm surfaces for plastering.

Columns.—All columns not enclosed in brickwork are to be wire-lathed. Suitable light iron furring is to be provided so as to offset the lathing at least 2 inches from the ironwork and finish round or square, as shown on the plans. The lathing is to be stiffened with ¼-inch solid ribs woven in every 7½ inches.

All Other Exposed Ironwork.—This is to be suitably encased with wire lathing supported whenever necessary by light iron furring, and in all cases providing an air-space of at least 1 inch between the ironwork and the plaster.

All of the above lathing is to be painted (galvanized), of No. 20 gauge and (2½ by 4) mesh and is to be securely laced to the furring with No. 19 galvanized lacing wire.

(All work here contemplated is to comply with the requirements of the Department of Building.)

SOLID PARTITIONS.

(METAL LATH AND STUDDING.)

697. This contractor is to provide all metalwork, and erect the partitions colored (gray) or otherwise marked on the plans, and leave them in perfect condition for the plasterer. Wood furring will be furnished in pieces of the proper size by the carpenter, but this contractor is to secure them to the metalwork. The above partitions are to be formed of studs of $\frac{3}{8}$ by $\frac{3}{4}$-inch channel-iron, placed 16 inches on centers for partitions (11) feet or less in height and 12 inches on centers for partitions more than (11) feet in height. All openings are to be framed with 1 by 1-inch by $\frac{3}{16}$-inch angle-irons.

1. The studs are to be securely fastened at top and bottom, and the grounds for door and window openings are to be firmly secured to the studs. Grounds for the nailing of base, chair-rail, picture-molds, etc., are to be fitted and fastened in place and made true and straight, $\frac{1}{2}$ an inch over the line of studs on the face side of the partitions and $\frac{1}{4}$ of an inch over the line of studs on the reverse side, the total thickness being $1\frac{1}{2}$ inches.

2. After the grounds are put on, the face side of each partition is to be covered with (——— metal lath); the sheets of lath are to come close together or lap on the horizontal joints and the vertical joints are to be broken properly; the lath is to be secured by nailing on with (trunk) nails, driven through alongside of studs and clinched around behind them, each nail being on the opposite side of a stud from the one above and below it. The metalwork is to be properly braced to hold it in position until the mortar has become firm.

[The bracing should be straight-edged flooring boards put on over the lath. Staples set around the studs and driven into the boards can be easily drawn afterward, leaving only 1-inch strips on the face of each partition and the staple holes on the reverse, to be filled in after the partitions have become rigid.]

[For wire lathing the specifications are to be as follows, instead of as in paragraph 2 above.]

3. After the grounds are put on, one side of the partitions is

to be covered with No. 20 painted (2½ by 4)-mesh wire lathing, stiffened with ¼-inch solid steel ribs woven in at intervals of 7½ inches, the rods running crosswise of the studs. The lathing is to be firmly secured to the studding with No. 19 galvanized lacing wire.

SPECIFICATIONS FOR THE "ROEBLING CONCRETE FLOOR ARCH SYSTEM."

698. [This specification is given as a guide in preparing specifications for this and similar floors. Most of the various fire-proofing companies have printed specifications for their systems, which they furnish to architects on application.]

The floor construction to be used in this building is to be that known as the "Roebling Concrete Floor Arch System," consisting of steel-ribbed wire cloth centerings and cinder concrete arches with ceilings suspended below the level of the floor beams. Continuous air-spaces between the floors and ceilings and around the girders are to be provided.

The wire centering for the floors is to consist of No. 22 four-warp two-filling wire cloth stiffened with from ⅜ to ½-inch steel rods woven into the cloth at intervals of about 9 inches. This centering is to be sprung in between each pair of I-beams in the form of an arch, with the ends of the rods abutting against the beams. The sheets are to be well lapped and securely laced. Over the crown of this centering one or more $\frac{5}{16}$-inch steel rods are to be laced parallel to the beams to secure proper longitudinal bracing.

In all spans over 3 feet 6 inches, at intervals of not over 3 feet, heavy galvanized wires are to be dropped down from the stiffening ribs of the arch to support the ceiling.

Over the wire arch so constructed, cinder concrete, mixed in the proportions of 1 part of high-grade Portland cement to 2½ parts of sharp sand and 6 parts of clean cinders, is to be laid, providing a thickness of not less than (3) inches at the crown of the arch. The concrete generally is to be levelled up to a height of (2 inches above) the tops of the floor beams where wood floors are specified, and to the specified levels where other than wood floors are designated.

Every alternate nailing-sleeper is to be imbedded in concrete so as to form a fire-stop. These sleepers are to be supplied, placed

in position over the beams and included in the carpenter's contract.

The floors are to be subjected to tests at any points that may be designated by the architect, and at any time after the concrete is fifteen days old. The floors are to develop in all cases a supporting strength of 1,000 pounds per square foot when the load is concentrated, and of 600 pounds per square foot when the load is uniformly distributed *over one-half of the span.*

SPECIFICATIONS FOR NATURAL CEMENTS.

[These specifications are given as guides for forms and methods of procedure in preparing specifications for this part of masonry building materials and construction. (See Article 168, Chapter IV, in which is given another specification for natural cements. The specification proposed by the American Society for Testing Materials is not given here, as its requirements are included in the form given in Article 168.)]

699. SPECIFICATIONS FOR NATURAL CEMENTS FOR THE NEW YORK STATE CANALS, 1896.—*Natural Hydraulic Cement* is to be of the best quality and of such fineness that 90 per cent will pass through a sieve of 2,500 meshes per square inch and 80 per cent through a sieve of 10,000 meshes per square inch.

Briquettes made of equal parts of natural hydraulic cement and crushed quartz, immersed in water as soon as they are sufficiently hard to sustain a 1/24-inch wire weighted with 1 pound, are to show a tensile strength of 65 pounds per square inch at the expiration of seven days; but briquettes showing less than such strength are to be held until twenty-eight days have elapsed, when, if they then show such strength as to sustain as many pounds per square inch above 125 as the seven-day test shows them to have fallen below 65, they are to be deemed to have passed this test. Briquettes made of neat cement are not to set so as to support a 1/12-inch wire with a load of ¼ of a pound in less than five minutes. Briquettes of neat cement are not to show checks or cracks when immersed in water for seven days after mixing.

700. SPECIFICATIONS FOR NATURAL CEMENT FOR THE RAPID TRANSIT SUBWAY, NEW YORK CITY, 1900-1901.—*Fineness.*—Ninety-five per cent is to pass a No. 50 sieve and 85 per cent at No. 100 sieve.

Tensile Strength.—At the end of seven days, one day in air, six

days in water, 125 pounds, neat. At the end of twenty-eight days, one day in air, twenty-seven days in water, 200 pounds, neat. When mixed 1 to 1 with quartz sand: at end of seven days, one day in air, six days in water, 100 pounds; at the end of twenty-eight days, one day in air, twenty-seven days in water, 150 pounds.

Soundness.—Tests for checking, cracking and color are to be made by molding, on plates of glass, cakes of neat cement about 3 inches in diameter, ½ an inch thick in the center, and very thin at the edges. One of these cakes, when it is set perfectly hard, is to be put in water and examined for distortion and cracks; and one is to be kept in air and examined for color, distortion and cracks.

701. SPECIFICATIONS FOR NATURAL CEMENT. ENGINEER CORPS, U. S. ARMY, 1901.—(1) The cement is to be a freshly packed natural (or Rosendale), dry and free from lumps. By natural cement is meant one made by calcining natural rock at a heat below incipient fusion and grinding the product to powder.

(2) The cement is to be put up in strong, sound barrels, well lined with paper so as to be reasonably protected against moisture, or in stout cloth or canvas sacks. Each package is to be plainly labelled with the name of the brand and of the manufacturer. Any package broken or containing damaged cement may be rejected, or accepted as a fractional package, at the option of the United States agent in local charge.

(3) Bidders are to state the brand of the cement which they propose to furnish. The right is reserved to reject a tender for any brand which has not given satisfaction in use under climatic or other conditions of exposure of at least equal severity to those of the work proposed.

(4) Tenders are to be received from manufacturers or their authorized agents only.

The following paragraph is to be substituted for paragraphs (3) and (4) above when cement is to be furnished and placed by the contractor:

(No cement, except established brands of high-grade natural cement which have been in successful use under climatic conditions similar to those of the proposed work, is to be used.)

(5) The average net weight per barrel is to be not less than 300 pounds. (West of the Allegheny Mountains this may be 265 pounds.) Sacks of cement are to have the same weight as 1

barrel. If the average net weight, as determined by test weighings, is found to be below 300 pounds (265 pounds) per barrel, the cement may be rejected, or, at the option of the engineer officer in charge, the contractor may be required to supply free of cost to the United States an additional amount of cement equal to the shortage.

(6) Tests may be made of the fineness, time of setting and tensile strength of the cement.

(7) *Fineness.*—At least 80 per cent of the cement is to pass through a sieve made of No. 40 wire, Stubbs' gauge, having 10,000 openings per square inch.

(8) *Time of Setting.*—The cement is not to acquire its initial set in less than twenty minutes and must have acquired its final set in four hours.

(9) The time of setting is to be determined from a pat of neat cement mixed for five minutes with 30 per cent of water by weight and kept under a wet cloth until finally set. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire 1/12 of an inch in diameter loaded with a ¼-pound weight. The final set is considered to have been acquired when the pat will bear, without being appreciably indented, a wire 1/24 of an inch in diameter loaded with a 1-pound weight.

(10) *Tensile Strength.*—Briquettes made of neat cement are to develop the following tensile strengths per square inch, after having been kept in air for twenty-four hours under a wet cloth and the balance of the time in water:

At the end of seven days, 90 pounds; at the end of twenty-eight days, 200 pounds.

Briquettes made of one part of cement and one part of standard sand by weight are to develop the following tensile strengths per square inch:

After seven days, 60 pounds; after twenty-eight days, 150 pounds.

(11) The highest result from each set of briquettes made at any one time is to be considered the governing test. Any cement not showing an increase of strength in the twenty-eight-day tests over the seven-day tests is to be rejected.

(12) The neat cement for briquettes is to be mixed with 30 per

cent of water by weight, and the sand and cement with 17 per cent of water by weight. After being thoroughly mixed and worked for five minutes the cement or mortar is to be placed in the briquette mold in four equal layers, each of which is to be rammed and compressed by thirty blows of a soft brass or copper rammer ¾ of an inch in diameter (or 7/10 of an inch square with rounded corners), weighing 1 pound. It is to be allowed to drop on the mixture from a height of about ½ an inch. Upon the completion of the ramming the surplus cement is to be struck off and the last layer smoothed with a trowel held in a nearly horizontal position and drawn back with sufficient pressure to make its edge follow the surface of the mold.

(13) The above are to be considered the minimum requirements. Unless a cement has been recently used on work under the direction of this office, bidders are to deliver a sample barrel for tests before the opening of the bids. Any cement showing by sample higher tests than those given are to maintain the average so shown in subsequent deliveries.

(14) A cement which fails to meet any of the above requirements may be rejected. An agent of the contractor may be present at the making of the tests, or, in case of the failure of any of them, they may be repeated in his presence. If the contractor so desires, the engineer officer may, if he deems it to the interest of the United States, have any or all of the tests made or repeated at some recognized standard testing laboratory in the manner above specified. All expenses of such tests are to be paid by the contractor, and all such tests are to be made on samples furnished by the engineer officer from cement actually delivered to him.

SPECIFICATIONS FOR PORTLAND CEMENTS.

[These specifications and extracts from the same are given as guides for forms and methods of procedure in preparing specifications for this part of the masonwork. There are now published so many specifications for work actually carried out that the engineer, architect or contractor will have no difficulty in finding numerous forms for use in comparison and for adaptation to any particular construction. (See Article 180, Chapter IV, in which is given an excellent specification for Portland cements. The specification proposed by the American Society for Testing Materials is not given

here, as its requirements are included in the form given in Article 180.)]

702. EXTRACT FROM SPECIFICATIONS FOR PORTLAND CEMENT FOR THE NEW YORK STATE CANALS, 1896.—*Portland Cement* is to be of the best quality and of such fineness that 95 per cent of the cement will pass through a sieve of 2 500 meshes to the square inch, and 90 per cent through a sieve of 10.000 meshes to the square inch. Portland cement when mixed neat and exposed one day in air and six days in water is to withstand a tensile stress of not less than 400 pounds to the square inch, and when mixed in the ratio of 3 pounds of clean, sharp sand to 1 pound of cement and exposed one day in air and six days in water, it is to withstand a tensile stress of not less than 125 pounds per square inch.

703. SPECIFICATIONS FOR PORTLAND CEMENT FOR THE RAPID-TRANSIT SUBWAY, NEW YORK CITY, 1900-1901.—*Fineness.*—Ninety-eight per cent is to pass a No. 50 sieve and 90 per cent a No. 100 sieve.

Tensile Strength.—When neat: At the end of one day in water after hard set, 150 pounds; at the end of seven days, one day in air, six days in water, 400 pounds; at the end of twenty-eight days, one day in air, twenty-seven days in water, 500 pounds. When mixed 2 to 1 with quartz sand: At the end of seven days, one day in air, six days in water, 200 pounds; at the end of twenty-eight days, one day in air, twenty-seven days in water, 300 pounds.

Chemical Analysis.—Chemical analysis is to be made from time to time and cement furnished is to show a reasonably uniform composition.

Soundness.—Tests for checking and cracking and for color are to be made by molding, on plates of glass, cakes of neat cement about 3 inches in diameter, ½ an inch thick in the center and very thin at the edges. One of these cakes when set perfectly hard is to be put in water and examined for distortion and cracks; and one is to be kept in air and examined for color, distortion and cracks. Another cake is to be allowed to set in steam for twenty-four hours and is then to be put in boiling water for twenty-four hours. Another cake is to be allowed to set hard in dry air for twenty-four hours and is then to be put in boiling water for twenty-four hours. Such cakes should at the end of the tests still adhere to the glass and show neither cracks nor distortion. A briquette,

in like manner, should be allowed to set hard in dry air for twenty-four hours, should then be boiled for twenty-four hours, kept for five days in water and show 350 pounds tensile strength.

SPECIFICATIONS FOR REINFORCED CONCRETE WORK.*

704. PORTLAND CEMENT—*Shipments.*—All shipments are to consist of well-seasoned cement, to meet the following specification:

Storage.—After delivery, all cement is to be stored in a suitable and convenient building to permit of easy access for proper inspection and identification of each shipment. At least twelve days' time is to be allowed for inspection and necessary tests before using.

Testing.—All cement is to be inspected either at the time of shipment or upon delivery, and is required to meet the tests herein prescribed before being used in the work. Where practicable, samples for testing may be taken from cars before leaving the cement works, the tests being made while the cement is in transit. The cost of said testing is to be borne by the owner.

Quality.—The cement is to equal in quality the best grade of American Portland cement; blending will not be tolerated.

Specific Gravity.—The cement is to have a specific gravity of not less than 3.10.

Fineness.—Not more than 8 per cent is to be retained upon a No. 100 sieve, nor more than 25 per cent upon a No. 200 sieve.

Set.—The cement is not to develop initial set in less than 30 minutes, and must have acquired its hard set in less than 8 hours.

Soundness; Accelerated Test.—Pats of neat cement are to be allowed to harden 24 hours in moist air, and are then to be subjected to the accelerated test as follows:

A pat is to be exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 2 hours, after which, before the pat cools, it is to be placed in the boiling water for 5 additional hours.

To pass the accelerated test satisfactorily, the pats are to remain firm and hard and show no signs of cracking, distortion or disintegration.

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* Taken and adapted from the specifications for the Edward Stern & Company's printing house, Philadelphia, Pa., erected in 1908, Messrs. Ballinger & Perrot, architects and engineers, Philadelphia, Pa. These specifications are reproduced by permission and through the courtesy of the architects.

SO_3.—The cement is not to contain more than 1.75 per cent of anhydrous sulphuric acid.

Tensile Strength.—Tensile tests are to be made on specimens prepared and maintained until tested at a temperature as near as practicable to 70 degrees Fahrenheit. Each specimen is to have an area of one square inch at the breaking section, and after being allowed to harden in moist air for 24 hours is to be immersed and maintained in water until tested. The sand used in preparing test-specimens is to be clean, sharp, crushed quartz, retained on a sieve of 30 meshes per lineal inch and passing through a sieve of 20 meshes per lineal inch.

The minimum tensile strength in pounds per square inch from test specimens is to be as follows:

NEAT CEMENT.

24 hours (in moist air)	150 lbs.
7 days (1 day in moist air, 6 days in water)	500 lbs.
28 days (1 day in moist air, 27 days in water)	600 lbs.

1 PART CEMENT, 3 PARTS SAND.

7 days (1 day in moist air, 6 days in water)	200 lbs.
28 days (1 day in moist air, 27 days in water)	280 lbs.

The average of sand-test specimens should develop a tensile strength from 10 to 40 per cent greater than the above minimums.

The rules recommended by the committee of the American Society of Civil Engineers on uniform tests of cement, as published in the proceedings of the said society for the month of January, 1903, are to be followed in making the above tests.

705. REINFORCED CONCRETE WORK.—*The Construction in General*.—Two methods of reinforced concrete construction are shown on the drawings. One is the "beam and girder construction" and the other is the "trough system of construction." Either system may be used, but the contractor is to state in his bid which system he proposes to adopt.

The contractor is to build the reinforced concrete work complete, as shown and required by the drawings, and in accordance with the regulations of the Philadelphia Bureau of Building Inspection.

The contractor is to furnish all labor and materials for the construction of the reinforced concrete work. He is to build all concrete work of whatsoever nature, excepting such footings as are

necessary for the underpinning of adjacent walls, as mentioned under the heading "Excavation, Foundation Masonry and Underpinning." All footings for walls, columns and partitions are to be included. The contractor is also to construct all area and other walls and all stairs of reinforced concrete where required by the drawings.

Falsework, Forms, Centering and Shores.—The contractor is to perform all labor and furnish all material for the construction of all forms and woodwork necessary to complete the concrete work. The beam, girder and column forms are to have sides at least 1½ inches thick, and the centering for the slabs is to consist of 1-inch material, tongued and grooved and battened together into panels. The forms are to be so constructed that they can be taken down without damaging the concrete or spalling the corners.

All forms are to be made true to line and are to be plumb and level.

The contractor is to provide bevelled strips in the bottom of all beam and girder forms and level the centering to form ceiling angles.

The method of centering is to permit of the earlier removal of the slab forms and sides of beams and the leaving in position of the shores and bottom forms of beams and girders. The latter are to remain in position at least two weeks in the most favorable weather, and as much longer as may be necessary.

The centering for the trough construction is to be made in any approved substantial manner and of such material and construction as will result in good work at the completion as well as at the commencement of the work.

A sufficient number of sets of centers or forms are to be used, as set forth in the "General Conditions," to carry on the work without delay or interruption.

A sufficient number of shores for the proper support of the forms, the dead weight of the wet concrete and the loads incidental to placing, are to be provided, and are to rest on solid foundations and remain in position until the concrete is sufficiently strong to support the weight of any upper floors which may depend upon such shores.

Care is to be exercised to see that the soil is suitable for the support of the bottom struts, and does not compress under the

load. If the latter condition prevails, trussed supports are to be provided for the forms.

Forms are to be sufficiently rigid to avoid any deflection whatever.

All the forms of the entire work are to be made with smooth dressed material, accurately put together and neatly fitted. No warped or twisted boards are to be used in the construction of the face of the molds, and all the molds are to be thoroughly swept and cleaned before the concrete is laid.

Any necessary form work is to be provided also for making openings where required for the installation of the equipment.

The bottom of each column box is to have one side left open until a few minutes before the concrete is poured, to permit of a proper adjustment of the rods, and to permit also any necessary inspection and cleaning. A pocket, also, is to be left in the bottom of girders and where necessary to clean out chips, etc., after the columns are poured.

All forms are to be washed off with water from a hose, or by other means, some time before and again immediately before the concrete is poured, in order to swell the wood to a tight fit and to remove any foreign substance.

Removal of Forms.—Forms are to be removed carefully in order to avoid scarring or spalling the concrete, and to prevent heavy forms from falling on and jarring the floors.

The concrete is to be sounded frequently with a hammer during the removal of the forms to make sure that the concrete is sound and well set. The floor above is not to be heavily loaded at the time the forms are removed. The props are not to be removed from under any floor until after three days after the floor next above has been cast.

Steel Reinforcement.—The girder, beam, column and column footing reinforcement is to consist generally of square cold-twisted or other deformed steel bars, together with stirrups and supports as required, and all as shown on the drawings. The slab reinforcement may be of deformed bars, wired together, or of wire mesh or expanded-metal.

Sections other than those shown on the drawings will be permitted to be used in a manner to suit different types of reinforcement. In all instances, however, the net sectional area of the metal reinforcement is to be the same as that designated on the drawings,

and the "center of action" of all the steel reinforcement in any slab must be at a distance of 1 inch from the soffit of the slab. The reinforcement of the beams and girders is to have at least 2 inches of concrete protection on the bottom and 1½ inches on the sides; and column reinforcement is to have 3 inches of such concrete protection.

If cold-twisted bars are used the reinforcement is to be what is known as "medium steel" made from original billets. These bars are to have a number of turns per foot, an elastic limit and an ultimate tensile strength approximately as follows:

Size.	No. of turns per foot.	Elastic limit. Pounds per sq. inch.	Ultimate strength. Pounds per sq. inch.
¼-inch	4	65,000	80,000
⅜ "	3½	60,000	75,000
½ "	3	60,000	75,000
⅝ "	2¼	60,000	75,000
¾ "	1½	60,000	75,000
⅞ "	1¼	55,000	70,000
1 "	1	50,000	70,000
1⅛-inches	⅞	50,000	70,000
1¼ "	¾	50,000	70,000

The bars are to have an elongation of at least twelve per cent, measured in 8 inches. The steel is to bend through 180 degrees over a pin whose diameter is 1½ times the diameter of the bar, without fracture on the outside of the bent portion.

If bars of other forms are used, they are to be of higher carbon steel and are to be made entirely of new billets, having elastic limits, ultimate strengths, elongations and bending properties as above.

The steel is to be tested by parties appointed by the architects and as often as the latter deem necessary; and any failure of the test specimen to meet the requirements is to be considered a sufficient cause for rejection. The cost of tests is to be borne by the owner.

None of the steel reinforcements is to be badly rusted, although a thin film of rust is not to be considered objectionable. If the steel is covered with loose or scaly rust, dirt or cement drippings it is to be cleaned with a wire brush. All bars are to be free from grease and paint.

Placing the Reinforcement.—All the steel tension members for beams, girders and lintels are to be fastened or wired together by

any suitable methods, and the stirrups need not be *rigidly* fastened to the principal members. All steel, however, is to be set in the molds before the concrete is poured, and the reinforcement is to be solidly supported or hung therein in such manner as to prevent shifting about when the concrete is tamped, care being taken to maintain the bars in their proper position.

All column rods are to lap 3 feet at their junction above each floor and are to be securely wired together.

Each floor beam and roof beam, where framed into a girder or column, is to have a ¾-inch tie-rod, 5 feet long, with hook ends turned down 3 inches, set in the top of the beam and projecting into it; these top rods are to extend to the far side of the girder or column.

All girders are to have, besides a full bearing at the columns for the reinforcement, two ¾-inch tie-rods, each 6 feet long, with hook ends running in both directions.

A sufficient amount of the reinforcement for beams, girders and lintels is to be bent upward toward the supports, to provide resistance to negative bending moments at or adjacent to these points.

Where an odd number of bars are used in two horizontal planes, the smaller number being staggered above the bottom bars and bent up, one of these upper bars may be extended 3 feet into each of the adjoining spans and take the place of the 5-feet lap-rods above specified.

The reinforcement for the trough construction is not to be provided with stirrups. One end of each rod is to be bent up at an angle of 45 degrees at a distance of 18 inches from the middle of the girder. The straight end of the bent portion is to extend over the middle of the girder at least 18 inches. The straight end of each rod also is to extend the same distance past the middle of the girder. In placing the bars in the trough construction the pair is to be so arranged that the bent portions come at opposite ends, thus forming a complete truss.

Besides the regular slab reinforcement, there are to be provided combination spacer and stool-lock wires of the pattern manufactured by the Philadelphia Steel and Wire Company. These are to be of No. 13 spring wire and are to be spaced 2 feet from center to center, extending in lines at right-angles to the slab-rods. If approved wire-mesh or expanded-metal is used for slab rein-

forcement, these spacers may be omitted. There are also to be provided rods or bars of the same section as the slab reinforcement and 5 feet long, placed 12 inches apart from center to center, over all girders and at right-angles to them.

All girders, beams and lintels are to be provided with stirrups, of sufficient size and in sufficient numbers, running the entire length of the beams and girders. There are to be a sufficient number of them, also, to resist the horizontal shearing stresses. The stirrups for the beams and girders are, in all instances, to be long enough to extend from the steel reinforcement in the lower part of a beam or girder a distance of at least 2 inches into the slab, and they are to have hook ends of at least 6-inch projection. Care is to be taken to have the stirrups of beams, girders and lintels sufficiently long to engage with the slab reinforcement; and the stirrups must either hook over the slab-rods or be punched or looped at the top so that these rods can thread through them. The stirrups are to be in no instance more than 4 feet apart at the middle part of the span; and are to be closer together if required by the drawings or if necessary to resist horizontal shear.

All slab reinforcement is to lap at least 18 inches at the joints over bearings.

The contractor is to provide ¼-inch "hairpin" stirrups 12 inches long, to be placed in the top of beams and girders where the work is stopped. These stirrups are to straddle the slab reinforcement, and are to be so spaced that the maximum distance between them is not over 18 inches. (These are not necessary if the work is stopped across beams and girders and parallel with the slab-rods. See note in regard to "Stopping Work.")

The contractor is to place the reinforcement sufficiently in advance of the pouring of the concrete to permit of inspection and correction by the architects if required.

Sockets, etc.—The contractor is to provide and imbed throughout the concrete beams and girders substantial ¾-inch cast-steel or malleable iron tapped sockets of approved design. The sockets are to be bolted to the bottom of the molds, placed near each bearing, and at intermediate distances apart of not more than 5 feet, or as shown on drawings. The bolts are to remain the property of the contractor.

Small cast-iron sockets, tapped ¼ of an inch, are to be provided

in all floor slab panels, about ten of these sockets being provided for each panel.

If the trough system of construction is employed, three slab-sockets are to be provided for every other beam.

The contractor is to provide at the middle of the span of each girder, and near the under side of the slab, four 1½-inch pipes extending entirely through the girder and placed about 2 inches from center to center. He is to provide two pieces of pipe of similar size and similarly located in the middle of the span of all beams.

All sockets and pipes are to be located to meet the approval of the architect or his representatives.

For the trough system, pipes are to be provided in girders only, at the bottom of the trough beams, and also the same total number of sockets, located as directed.

The contractor is to state the allowance that is to be made if all sockets and pipes are omitted, as required by the "Form of Proposal."

Pipe Sleeves.—The contractor is to place sleeves on the slab centering in order to provide holes for the use of plumbing, steam and sprinkler pipes, electrical conduits, etc., said sleeves being furnished by the contractors for the respective kinds of work, and drawings also being furnished to the contractor showing the proper location of said sleeves.

Shop Drawings.—The contractor is to promptly submit shop drawings in duplicate to the architect for approval; and any changes required are to be made before the work proceeds. The shop drawings are to conform to the architect's drawings as to the concrete dimensions, sectional area and location of steel reinforcement, although equivalent areas may be permitted in order to accommodate bars or meshes of shapes differing from those indicated on the drawings. These drawings are to show in detail all the reinforcement, the manner of fastening and supporting in the forms, the position of bends and the location and size of the stirrups.

The cement is to be provided by the contractor and is to comply with the requirements elsewhere specified.

The sand is to be clean, coarse bank sand, Jersey gravel or coarse river gravel, free from dirt or other impurities, and containing

less than five per cent of loam as approved. Equal parts of bar sand and Jersey gravel are preferred.

The broken stone is to consist of clean trap rock or equally hard stone, not of lime formation, and as approved by the architect. The stone used for footings or for other concrete in large masses may be of a size to pass through a 1½-inch ring. The remaining stone is to be so broken that it will pass through a ¾-inch ring, and one-fourth of the whole is to be less than one-half the maximum size and free from crusher dust.

If the stone is the "run of the crusher," varying gradually from about ⅛-inch size to the maximum, the proportion of sand to stone is to be changed to meet the approval of the architect.

Proportions.—The reinforced concrete is to be mixed in the proportions of one part of cement, two parts of sand and four parts of broken stone. Suitable means are to be provided, as approved by the architect, for accurately measuring the respective ingredients.

Mixing.—An approved batch mixer, such as the Ransome, McKelvey, Smith or Chicago types, and of sufficient capacity, is to be used. A competent man is to be in charge of the mixing. Care is to be exercised in adding water to obtain the proper consistency. Water should be added by measure, not by hose, in order to avoid non-uniformity.

Where the quantity of work is small, hand-mixing may be permitted by the architect, in which case the cement and sand are to be turned over with shovels and raked twice while dry and twice while being wet; the stone is to be wet separately, and the whole turned over together twice with shovels and rakes.

Care is to be exercised to keep the gravel or sand and broken stone in distinct and separate bins or piles.

Test Cubes.—The contractor, whenever required by the architects, is to make and deliver to the testing laboratory 6-inch concrete test cubes, said cubes being made from the regular mixture used in the work.

Contractor's Plant.—The contractor is to provide a suitable hoist and all other tools and implements for handling the concrete with the greatest possible despatch.

Putting the Concrete in Place.—The forms are to be thoroughly wet some time before, and again immediately before the concrete

is poured, in order that they may swell and that the joints may be nearly water-tight.

The concrete is to be well tamped in position and the molds thoroughly filled and flat-spaded, so that when the forms are removed the work will be smooth on the face and solid throughout.

The concrete work, where exposed in fire-escapes and toilet-rooms, is to have the rough parts smoothed off and the voids filled flush, leaving a smooth finish. The tops of the roof slabs, where there is reinforced concrete roof construction, are to be made smooth preparatory to the laying of the felt roof. All columns, girders and beams are to be plumb, straight and true to line, special care being exercised in these particulars with the column and wall forms.

In stopping the work over beams or girders the slab-rods are to be of sufficient length to extend over and furnish a bond or tie into the next span to a distance at least 12 inches beyond the middle line of such beams or girders.

Columns are to be filled to the bottom of the beams, the concrete being thoroughly churned with a pole. After being filled to this height they are to set for several hours to allow for settlement, after which the beam, girder and slab forms are to be filled.

Slabs are to be poured on the same day the girders and beams are poured and before the concrete has begun to set in the latter. In case any slabs are not poured on the same day, the girders and beams are to be cleaned with water, well soaked and grouted on top with neat cement rubbed in with brushes or brooms; after that a thin layer of cement mortar is to be trowelled in and the slabs immediately laid.

In joining new work to old work cement mortar is to be used.

The contractor is to remove all fins from the concrete work after it has set and the forms have been removed.

Stopping Work.—In stopping a day's work either of the following methods is to be employed: (1) Slabs are to be stopped off along the middle line of beams and girders, pockets are to be left in girders to form bearings for beams and bearings for beams and girders are to be formed on columns; or (2) the work may be stopped where necessary across the middle line of beams and girders and on slabs parallel with the main slab-rods. Molded cement blocks may be used as separating dams under and between reinforc-

ing bars, or stiff cement dams may be provided under and between bars and wood blocking above to make vertical stops.

Caution.—After the floor slabs have begun to set they are not to be walked on or wheeled over until hard, as otherwise their strength is seriously injured. If traffic over them is unavoidable, boards are to be provided for the purpose of distributing the weights.

Laying Concrete in Warm Weather.—The surface of concrete floors laid during warm weather is to be wet twice daily, Sundays included, during the first week. The broken stone, if hot and dry, is to be wet before going to the mixer.

Laying Concrete in Cold Weather.—Reinforced concrete should not be laid, if it is possible to avoid doing so, when the temperature is below 33° Fahr. Extra precautions are to be taken during cold weather. The water should be heated to about 100° Fahr. The stone and sand, if covered with ice or snow, should be heated by steam immediately before mixing.

Should the temperature drop below freezing, or the United States Weather Bureau predict such weather, fresh concrete is to be protected by a thick layer of hay or straw above it and salamander fires or other heat provided below. The openings are to be covered where necessary.

A quantity of hay or straw should be kept on hand for use in covering the work.

Concrete frozen while fresh and found to be injured is to be removed at the contractor's expense.

Forms are to be left in place during cold weather until the concrete has obtained a hard natural set.

Lintels.—All concrete lintels, where they extend above a floor, are to be cast at the same time the slabs are cast. The exterior faces of the lintels on ——— Street are to be composed of a 1-2-4 mixture of cement, light sand and crushed granite. The granite pieces are to be not over a ⅜-inch size. When the face-work has thoroughly set it is to be dressed with 6-cut patent hammers to a depth sufficient to remove the outside surface entirely and to leave exposed the texture of the concrete facing.

Gussets.—The roof gussets are to be formed where shown of concrete composed of 1 part of cement, 3 parts of sand and 6

parts of clean, hard cinders, laid fairly wet and with a smooth surface.

Stair Construction.—The contractor is to construct the stairs throughout, where indicated, of reinforced concrete, and to furnish all the necessary metal reinforcing for the same.

Any necessary sockets for pipe-railings or other fastenings are to be placed where required during the construction of the work.

The treads and risers are to be finished with a cement surface composed of 1 part of cement to 2 parts of sand. The surface on the treads is to be 1½ inches thick and that on the risers ½ an inch thick. The concrete steps throughout are to be arranged with a projecting and rounded nosing.

All stairs and landings, where the walls are to be plastered, are to have a cement base, 6 inches high from the nosing, formed along the wall and neatly finished.

Safety Treads.—The contractor is to place in position the "Mason Safety Treads," as specified under that heading.

Platforms of Balconies.—Concrete floors, composed of 1 part of cement, 2 parts of sand and 4 parts of clean, hard furnace cinders, are to be provided upon the steel framing for balconies; and they are to be finished with a 1-inch surfacing of cement as elsewhere specified. The under sides of platforms are to have a cement brush-finish.

Copper Ties.—The contractor is to provide and place in the forms copper ties to secure the face brickwork to the concrete construction. These copper ties are to be ¾ by $\frac{1}{16}$-inch in cross-section by 8 inches in length. The ends of the copper ties are to be bent over to secure a hold in the mortar joints of the brickwork. The ties are to project at least 4 inches into the concrete work, and are to be placed so that there will be one tie to each two square feet of face brickwork.

Where cesspools are marked, as in areas, etc., the floors are to be graded to drain to them.

Wearing Surface.—The concrete is to be covered with a 1-inch surface (1-inch strips are to be used), composed of Portland cement, well mixed with clean, sharp, coarse granite or crushed trap-rock and sand in the proportion of one part of cement to one part of rock and one part of sand and finished with an even-floated surface of uniform shade, and laid off in blocks as directed.

All cement floors on reinforced concrete, where cement floors are marked, including toilet-rooms, are to be similarly finished with a 1-inch cement finish; this and any other cement finish on reinforced concrete slabwork is to be placed on 2 inches of cinder concrete filling composed of materials as elsewhere specified.

The cement finish or wearing surface is, in all cases, to be laid before the concrete base has set, in order to obtain a perfect bond.

The floors of toilet-rooms are to be graded to drain and are to be finished with a 2½-inch coved base around the walls and partitions. The coved base is to be finished flat on top to receive a ⅞-inch rubbed-slate base-board.

Concrete Sills, Copings, etc.—Concrete sills are to be provided under all tin-lined fire-doors and wherever marked on the plans. These sills are to be of sufficient width to cover the threshold and the thickness of the doors and are to have angle edges as specified under "Iron and Steel Work." All sills are to be constructed as shown on detail drawings.

A concrete coping, at least 10 inches in thickness, is to be provided and placed on the top of the stack, and finished on top with a smooth surface and wash.

Cinder Concrete Filling.—Cinder concrete is to be provided between wood sleepers where the plans show wood floors laid over reinforced concrete. This concrete is to be brought up flush with the top of the sleepers. All filling is to be made of clean furnace clinkers, sand and cement, in the proportions of one of cement, three of sand and seven parts of cinders. The cinder concrete is to be well manipulated and tamped in position.

Cinder concrete mixed as above is to be placed also upon the reinforced concrete slabs, where cement floors are marked to receive the cement finish.

Fire-proofing.—The contractor is to provide and place concrete fire-proofing for all steel beams, girders or other structural steel work where the same is required by the plans, and is to provide all the necessary expanded-metal and light metalwork for securing the same in place.

Cement Pavements.—The contractor is to repave the sidewalks where cement pavements are called for by the plans. These pavements are to be laid on 16-inch beds of clean boiler cinders, thoroughly tamped or rolled, and are to consist of concrete 4 inches

in thickness and of the same composition as specified for similar work in the basement. The finishing coat is to be 1 inch in thickness, laid with strips, marked off in blocks and indented. The concrete for the base of the pavement is to be cut in blocks all the way through. Expansion-joints are to be provided every fifty feet and filled with asphalt.

The finishing coat is to be put on before the concrete base has its final set, and the entire pavement is to be true and properly graded.

A concrete curb is to be provided throughout as required by the plans.

The curb is to be placed in the ground to a depth of at least 2 feet 6 inches and smoothly finished with a 1-inch coat of cement finish, as specified for the basement floor. It is to be provided with a quarter-round galvanized-iron armored corner-bead, made for this purpose and of an approved pattern. This corner-bead is to be furnished as specified under this heading.

CONCRETE BUILDING BLOCKS.*

706. RULES AND REGULATIONS GOVERNING THE USE AND MANUFACTURE OF HOLLOW CONCRETE BUILDING BLOCKS. (See also Article 633.)—1. *Composition and Use.*—Hollow concrete building blocks may be used for buildings six stories or less in height where said use is approved by the Bureau of Building Inspection; provided, however, that such blocks are composed of at least one (1) part of standard Portland cement, and not more than five (5) parts of clean, coarse, sharp sand or gravel, or of a mixture of at least one (1) part of Portland cement to five (5) parts of crushed rock or other suitable aggregate; and provided, further that this section does not permit the use of hollow blocks in party-walls. Said party-walls are to be built solid.

2. *Percentage of Hollow Spaces.*—All material is to be fine enough to pass through a ½-inch ring and is to be free from dirt or foreign matter. The material composing such blocks is to be properly mixed and manipulated, and the volume of hollow spaces in said blocks is not to exceed the percentage given in the following

* Taken and adapted from the "Laws and Ordinances Relating to the Bureau of Building Inspection" of the City of Philadelphia, Pa., 1907. Philadelphia and Denver are the first two cities which have given exhaustive study to concrete building blocks with a view to formulating regulations governing their use in building construction.

table for walls of different heights. In no case are the walls or webs of a block to be less in thickness than one-fourth of the height. The figures given in the table represent the percentage of such hollow spaces for walls of different heights.

Stories.	1st.	2d.	3d.	4th.	5th	6th.
1 and 2	33	33				
3 and 4	25	33	33	33		
5 and 6	20	25	25	33	33	33

3. *Thickness of Walls.*—The thicknesses of walls for any building in which hollow concrete blocks are used are to be not less than is required by law for the thicknesses of brick walls.

4. *Bonding and Tests.*—Where the face only is of hollow concrete building blocks and the backing is of brick, the facing of the hollow concrete blocks is to be strongly bonded to the brickwork either with headers projecting four (4) inches into the brickwork, every fourth course being a heading course, or with approved ties; no brick backing is to be less than eight (8) inches in thickness. Where the walls are made entirely of hollow concrete blocks, but where the said blocks have not the same width as the walls, every fifth course is to extend through the wall, forming a secure bond. All walls in which blocks are used are to be laid up in Portland cement mortar.

5. *Age of Blocks.*—All hollow concrete building blocks before being used in the construction of any building in the City of Philadelphia must have attained the age of at least three (3) weeks.

6. *Blocks Solid Under Concentrated Loads.*—Wherever girders or joists rest upon walls so that there is a concentrated load of over two (2) tons on the blocks, those supporting the girder or joists are to be made solid. Where such concentrated load exceeds five (5) tons, the blocks for two (2) courses below, and for a distance of at least eighteen inches on each side of said girder, are to be made solid. Where the load on the wall from the girder exceeds five (5) tons, the blocks for three (3) courses beneath it are to be made solid with a material similar to that used in the blocks. Wherever walls are decreased in thickness the top course of the thicker wall is to be solid.

7. *Maximum Load and Crushing Strength.*—Provided always: that no wall, or any part thereof, composed of hollow concrete blocks is to be loaded in excess of eight (8) tons per superficial

foot of the area of such blocks, including the weight of the wall; and that no blocks having an average crushing strength of less than 1,000 pounds per square inch of area at the age of twenty-eight (28) days are to be used; and that no deduction is to be made for the hollow spaces in figuring the area.

8. *Piers, Buttresses, Sills and Lintels.*—All piers and buttresses which support loads in excess of five (5) tons are to be built of solid concrete blocks for such distance below as may be required by the Bureau of Building Inspection. Concrete lintels and sills are to be reinforced with iron or steel rods in a manner satisfactory to the Bureau of Building Inspection, and any lintels spanning over 4 feet 6 inches in the clear are to rest on solid concrete blocks.

9. *Testing Blocks and Filing Certificates.*—Provided: that no hollow concrete building blocks are to be used in the construction of any building in the City of Philadelphia, unless the maker of said blocks has submitted his product to the full test required by the Bureau of Building Inspection, and has placed on file with said Bureau of Building Inspection a certificate from a reliable testing laboratory showing that samples from the lot of blocks to be used have successfully passed the requirements of the Bureau of Building Inspection, and that a full copy of the test has been filed with the Bureau.

10. *Brand.*—A brand or mark of identification is to be impressed in, or otherwise permanently attached to, each block for purposes of identification.

11. *Approval Limited to Four Months.*—No certificate of approval is to be considered in force for more than four months, unless there be filed with the Bureau of Building Inspection, in the City of Philadelphia, at least once every four months following, a certificate from some reliable physical testing laboratory showing that the average of three (3) specimens tested for compression, and three (3) specimens tested for transverse strength, comply with the requirements of the Bureau of Building Inspection of the City of Philadelphia. The samples are to be selected either by a Building Inspector or by the laboratory from blocks actually going into construction work. Samples are not to be furnished by the contractors or builders.

12. *Tests of Cements Used.*—The manufacturer and user (or either the manufacturer or the user) of any such hollow concrete blocks as are mentioned in this regulation, at any and all times

required, are to have such tests made of the cements used in making such blocks, or such further tests of the completed blocks, or of each of these, at their own expense, and under the supervision of the Bureau of Building Inspection, as the Chief of said Bureau requires.

13. *Portland Cement to Be Used.*—The cement used in making said blocks is to be Portland cement, capable of passing the minimum requirements as set forth in the "Standard Specifications for Cement" by the American Society for Testing Materials.

14. *Defective Blocks Condemned.*—Any and all blocks, samples of which, on being tested under the direction of the Bureau of Building Inspection, fail to stand at twenty-eight (28) days the tests required by this regulation, are to be marked "condemned" by the manufacturer or user, and are to be destroyed.

15. *Inspection of Blocks and Testing of Samples.*—No concrete blocks are to be used in the construction of any building in the City of Philadelphia until they have been inspected, and average samples of the lot tested, approved and accepted by the Chief of Building Inspectors.

706. SPECIFICATIONS GOVERNING THE METHOD OF TESTING HOLLOW BLOCKS.—1. *General Considerations.*—These regulations are to apply to all such new materials as are used in building construction in the same manner and for the same purposes as stone, brick and concrete are now authorized by the building laws, to be used, when said new materials to be substituted depart from the general shape and dimensions of ordinary building bricks; and they are to apply more particularly to that form of building material known as "hollow concrete blocks," manufactured from cement and a certain addition of sand, crushed stone or similar material.

2. *Applications Filed.*—Before any such material is used in buildings, an application for its use and for a test of the same is to be filed with the Chief of the Bureau of Building Inspection. A description of the material, a brief outline of its manufacture and the proportions of the materials used are to be embodied in the application.

3. *Tests Required.*—The material is to be subjected to the following tests: transverse, compression, absorption, freezing and fire. Additional tests may be called for when, in the judgment of the Chief of the Bureau of Building Inspection, the same may be

necessary. All such tests are to be made in some laboratory of recognized standing, under the supervision of the engineer of the Bureau of Building Inspection. The tests are to be made at the expense of the applicant.

4. *Results of Tests Filed.*—The results of the tests, whether satisfactory or not, are to be placed on file in the Bureau of Building Inspection. They are to be open to inspection upon application to the Chief of the Bureau, but need not necessarily be published.

5. *Samples for Tests.*—For the purposes of the tests at least twenty (20) samples or test pieces are to be provided. Such samples must represent the ordinary commercial product. They may be selected from stock by the Chief of the Bureau of Building Inspection, or his representative, or may be made in his presence, at his discretion. The samples are to be of the regular size and shape used in construction. In cases where the material is made and used in special shapes and forms, too large for testing in the ordinary machines, smaller-sized specimens are to be used, as may be directed by the Chief of Building Inspection, to determine the physical characteristics specified in Section 3.

6. *Tests to Be Made in Sixty Days.*—The samples may be tested as soon as desired by the applicant, but in no case later than sixty (60) days after manufacture.

7. *Weight.*—The weight per cubic foot of the material is to be determined.

8. *Manner of Testing.*—Tests are to be made in series of at least five, except that in the fire tests a series of two (four samples) are sufficient. Transverse tests are to be made on full-sized samples. Half samples may be used for the crushing, freezing and fire tests. The remaining samples are to be kept in reserve, in case unusual flaws or exceptional or abnormal conditions make it necessary to discard certain of the tests. All samples are to be marked for identification and comparison.

9. *Transverse Test.*—The transverse test is to be made as follows: The samples are to be placed flatwise on two rounded knife-edge bearings set parallel and seven inches apart. Loads transmitted through a similar rounded knife-edge are then to be applied on top, midway between the supports, until the sample is ruptured. The modulus of rupture is then to be determined by multiplying the total breaking load in pounds by twenty-one (three times the distance between the supports, in inches) and by dividing the product

thus obtained by twice the product of the width in inches by the square of the depth in inches. The formula to be used for the modulus of rupture is

$$R = \frac{3\,W\,l}{2\,b\,d^2}$$

No allowance is to be made for the hollow spaces in figuring the modulus of rupture.

10. *Compression Test.*—The compression test is to be made as follows: Samples are to be so cut from blocks that they contain a full web section. The sample is to be carefully measured, bedded flatwise in plaster of Paris to secure a uniform bearing in the testing machine and then crushed. The total breaking-load is to be then divided by the area in compression in square inches. No deduction is to be made for hollow spaces; the area is to be considered as the product of the width by the length.

11. *Absorption Test.*—The absorption test is to be made as follows: The sample is to be first thoroughly dried to a constant weight. The weight is to be carefully recorded. It is then to be placed in a pan or tray of water, face downward, to a depth of not more than ½ an inch. It is to be again carefully weighed at the following periods: thirty minutes, four hours and forty-eight hours, respectively, from the time of immersion, being replaced in the water in each case as soon as the weight is taken. Its compressive strength, while still wet, is then to be determined at the end of the forty-eight-hour period in the manner specified in Section 10.

12. *Freezing Test.*—The freezing test is made as follows: The sample is to be immersed, as described in Section 11, for at least four hours and then weighed. It is then to be placed in a freezing mixture or in a refrigerator, or otherwise subjected to a temperature lower than 15 degrees Fahr. for at least 12 hours. It is then to be removed and placed in water, where it is to remain for at least one hour, the temperature of the water being at least 150 degrees Fahr. This operation is to be repeated ten (10) times, after which the sample is to be again weighed while still wet from the last thawing. Its crushing strength is then to be determined as called for in Section 10.

13. *Fire Test.*—The fire test is to be made as follows: Two

samples are to be placed in a cold furnace in which the temperature is gradually raised to 1700 degrees Fahr. The test piece is to be subjected to this temperature for at least 30 minutes. One of the samples is then to be plunged into cold water (whose temperature is from about 50 to 60 degrees Fahr.) and the results noted. The second sample is to be permitted to cool gradually in air and the results noted.

14. *Modulus of Rupture and Ultimate Compressive Strength.*—The following requirements are to be met to secure an acceptance of the materials: The modulus of rupture for concrete blocks 28 days old is to average 150 and is not to fall below 100 pounds per square inch in any case. The ultimate compressive strength at 28 days is to average 1,000 pounds per square inch and is not to fall below 700 pounds per square inch in any case. The percentage of absorption (being the weight of water absorbed divided by the weight of the dry sample) is not to average higher than 15 per cent and is not to exceed 20 per cent in any case. The reduction of compressive strength is to be not more than 33⅓ per cent, except that when the lower figure is still above 1,000 pounds per square inch the loss in strength may be neglected. The freezing and thawing process is not to cause a loss in weight greater than 10 per cent, nor a loss in strength of more than 33⅓ per cent; except that when the lower figure is still above 1,000 pounds per square inch, the loss in strength may be neglected. The fire test is not to cause the material to disintegrate.

15. *Conditions for Approval.*—The approval of any material is to be given under the following conditions only:

a. A brand mark for identification is to be impressed on, or otherwise attached to, the material.

b. A plant for the production of the material is to be in full operation when the official tests are made.

c. The name of the firm or corporation and the names of the responsible officers are to be placed on file with the Chief of the Bureau of Building Inspection, and changes in same promptly reported.

d. The Chief of the Bureau of Building Inspection may require full tests to be repeated on samples selected from the open market when, in his opinion, there is any doubt as to whether the product is up to the standard of these regulations; and the manufacturer is to submit to the Bureau of Building Inspection, once in at least

every four months, a certificate of tests showing that the average resistance of three specimens to cross-breaking and crushing are not below the requirements of these regulations. Such tests are to be made by some laboratory of recognized standing on samples selected either by a Building Inspector or by the laboratory, from material actually going into the construction, and not on those furnished by the manufacturer.

e. In case the results of tests made under this condition (d) show that the standard of these regulations is not maintained, the approval of this Bureau for the manufacture of said blocks is to be at once suspended or revoked.

APPENDIX.

The tables of the Appendix relate to and give additional data on the subjects relating principally to cements, building stones and baked-clay products treated in Chapters IV, V, VII and VIII.

TABLE A.*

The following table shows the quantity and the value of the natural cement made in the United States in 1904, 1905 and 1906: The combinations of figures for total State productions neces-

TABLE A.*

PRODUCTION, IN BARRELS, OF NATURAL CEMENT IN 1904, 1905 AND 1906, BY STATES.

State	1904			1905			1906		
	No. of w'ks	Quantity	Value	No. of w'ks	Quantity	Value	No. of w'ks	Quantity	Value
Georgia	2	66,500	$37,750	3	89,167	$51,040	3	a180,500	$98,075
Illinois	3	360,308	113,000	3	368,645	116,549	3	365,843	118,221
Indiana	13	735,906	367,953	12	527,600	211,040	12	600,000	240,000
Kansas	2	210,922	79,456	2	230,686	110,750	2	238,311	129,781
Kentucky	2	264,104	132,052	2	207,500	83,000	2	170,194	95,539
Maryland	4	65,000	32,500	4	55,324	28,694	4	a63,350	32,675
Minnesota	2	138,000	65,620	2	115,314	57,643	2	....	....
Nebraska	1	....	....	1	....	....	1	....	....
New York	19	1,911,402	1,138,667	16	1,926,837	1,332,809	16	a1,515,866	1,055,785
North Dakota	1	....	....	1	....	....	1	....	....
Ohio	1	....	....	1	64,791	51,235	1	....	....
Pennsylvania	5	770,897	298,533	5	748,057	306,555	4	744,403	560,534
Texas	1	....	....	1	....	....	1	....	....
Virginia	2	93,292	59,619	2	....	....	1	....	....
West Virginia	1	....	....	1	....	....	....	....	....
Wisconsin	2	250,000	125,000	2	139,128	63,737	2	177,330	92,560
Total	61	b4,866,331	2,450,150	58	c4,473,049	2,413,052	55	4,055,797	2,423,170

a As shown by the returns, a small quantity of hydraulic lime was produced in Georgia, Maryland and New York. The combined output of these States is 40,800 barrels, valued at $19,300, and is included in the total of natural cement production for 1906.

b The States combined for 1904 and 1905 are noted in the text of the reports for those years.

c The States wherein the cement product was combined with that of some other State for 1906 are given in the text of the government report.

* Taken from "Mineral Resources of the United States," for the year 1906.

sary to conceal individual outputs in 1906 are as follows:

Wisconsin, North Dakota and Minnesota are grouped together; Kentucky, Ohio and Virginia form a second group; and Texas and Kansas complete the combinations. As is the custom, the State making the largest contribution to the total in these groups carries the entire quantity.

New York ranks first, as always, in this production, with Pennsylvania second, and Indiana third.

TABLE B.*

GEOGRAPHIC DISTRIBUTION OF THE PORTLAND CEMENT INDUSTRY IN 1905 AND 1906.

	Number of plants operating		Output, in barrels		Percentage of total output	
	1905	1906	1905	1906	1905	1906
East	30	31	19,589,675	25,483,025	55.6	54.9
Central	32	34	10,723,802	14,030,665	30.4	30.2
West	7	8	2,470,349	3,834,656	7.0	8.2
Pacific coast	3	4	1,225,429	1,310,435	3.5	2.8
South	7	7	1,237,557	1,804,643	3.5	3.9
Total	79	84	35,246,812	46,463,424	100.00	100.0

* Taken from "Mineral Resources of the United States," for 1906.

TABLE C.*

The following table is designed to show the quantity and value of the Portland cement made in those States which were producers in 1904, 1905 and 1906:

As heretofore, the production of those plants which are the only ones in their States are so combined that the figures may not be published in a form which will reveal individual production.

The cards of request for figures and information annually issued state that all facts and data sent in are regarded as confidential unless there is a special understanding to the contrary. Individual figures showing quantity or value of production are very seldom published, and if in rare instances such a publication is considered desirable it is never made without express permission from the producer.

In the following table the outputs of Alabama, Georgia, West Virginia, and Virginia are combined; the production of Kentucky is given with that of Missouri; Colorado, Utah, Texas, South Dakota, and Arizona are combined; and in each instance the total sum of the combined figures is placed against the name of the State that contributed the largest quantity of cement to that total.

In 1906 there was great activity in the Portland cement industry. States which have heretofore not produced cement began the erection of Portland cement plants; mills that were making their initial runs did well; and some of the centers of activity increased their productive capacity, either by constructing new plants or by remodeling old ones.

Indian Territory, Iowa and Arizona appear in 1906 for the first time in the list of cement-producing States.

TABLE C.*

PRODUCTION, IN BARRELS, OF PORTLAND CEMENT IN THE UNITED STATES IN 1904-1906, BY STATES.

State	1904 *a*			1905 *a*			1906 *b*		
	No. of w'ks	Quantity	Value	No. of w'ks	Quantity	Value	No. of active w'ks	Quantity	Value
Alabama	1	....	....	1	....	....	1	....	....
Arizona	....	....	....	....	....	....	1	....	....
California	3	1,014,558	$1,446,909	3	1,225,429	$1,671,816	3	1,310,435	$2,110,294
Colorado	1	490,294	638,167	1	786,232	1,172,027	1	1,146,396	2,034,382
Georgia	1	....	....	1	....	....	1	....	....
Illinois	5	1,326,794	1,449,114	5	1,545,500	1,741,150	4	1,858,403	2,461,494
Indiana	4	1,350,714	1,232,071	6	3,127,042	3,134,219	6	3,951,836	4,964,855
Kansas	2	2,643,939	2,134,612	4	....	....	4	3,020,862	3,908,708
Kentucky	1	....	....	1	....	....	1	....	....
Michigan	16	2,247,160	2,365,656	16	2,773,283	2,921,507	14	3,747,525	4,814,965
Missouri	2	....	....	2	3,879,542	4,164,974	2	3,350,000	3,260,000
New Jersey	3	2,799,419	2,099,564	3	3,654,777	2,775,768	3	4,423 648	4,445,364
New York	11	1,362,514	1,257,561	11	2,111,411	2,044,253	9	2,414,362	2,725,744
Ohio	7	910,297	987,899	8	1,312,977	1,390,481	8	1,422,901	1,709,918
Pennsylvania	17	11,496,099	8,969,206	18	13,813,487	11,195,940	19	18,645,015	18,598,439
South Dakota	1	....	....	1	....	....	1	....	....
Texas	2	....	....	3	....	....	2	....	....
Utah	1	....	....	1	....	....	1	....	....
Virginia	1	864,093	774,360	1	1,017,132	1,033,732	1	1,172,041	1,432,023
Washington	....	....	....	1	....	....	1	....	....
West Virginia	1	....	....	1	....	....	1	....	....
Total	81	26,505,881	23,355,119	89	35,246,812	33,245,867	84	46,463,424	52,466,186

a The States combined for 1904 and 1905 are mentioned in the text of the reports for those years.
b The States combined for 1906 are given in the text below.

* Taken from "Mineral Resources of the United States," for 1906.

TABLE D.*

The table which follows shows the growth of the Portland cement industry in the United States. Its form was originally determined by the fact that the cement production was confined mainly to certain well-defined centers, but changes in conditions since 1900 have necessitated a change in form.

Under "All Other Sections" is included the production of Alabama, Arizona, California, Colorado, Georgia, Illinois, Indiana, Kansas, Kentucky, Missouri, South Dakota, Texas, Utah, Virginia, West Virginia and of other counties in Pennsylvania than Lehigh and Northampton Counties.

TABLE D.*

DEVELOPMENT OF THE PORTLAND CEMENT INDUSTRY IN THE UNITED STATES SINCE 1890.

Section	1890			1900		
	No. of w'ks	Quantity (barrels)	Percentage	No. of w'ks	Quantity (barrels)	Percentage
New York	4	65,000	19.4	8	465,832	5.5
Lehigh and Northampton Counties, Pa., and Warren County, N. J.	5	201,000	59.9	15	6,153,629	72.6
Ohio	2	22,000	6.5	6	534,215	6.3
Michigan	....	....	....	6	664,750	7.8
All other sections	5	47,500	14.2	15	663,594	7.8
Total	16	335,500	100.0	50	8,482,020	100.0

Section	1905			1906		
	No. of w'ks	Quantity (barrels)	Percentage	No. of w'ks	Quantity (barrels)	Percentage
New York	11	2,111,411	6.0	9	2,414,362	5.2
Lehigh and Northampton Counties, Pa.	15	13,713,910	38.9	17	18,360,965	39.5
New Jersey	3	3,654,777	10.4	3	4,423,648	9.5
Ohio	8	1,312,977	3.7	8	1,422,901	3.1
Michigan	16	2,773,283	7.9	14	3,747,525	8.1
All other sections	36	11,680,454	33.1	33	16,094,023	34.6
Total	89	35,246,812	100.0	84	46,463,424	100.0

* Taken from "Mineral Resources of he United States," for 1906.

TABLE E.*

The following table shows the total production of puzzolan or slag cement in the United States in 1904, 1905 and 1906, together with the number of plants in each State:

TABLE E.*

PRODUCTION, IN BARRELS, OF SLAG CEMENT IN THE UNITED STATES IN 1904-1906, BY STATES.

State	1904			1905			1906		
	No. of w'ks	Quantity	Value	No. of w'ks	Quantity	Value	No. of w'ks	Quantity	Value
Alabama....	2	187,677	$141,402	2	....	....	2	....	....
Illinois......	1	....	....	1	106,236	$80,616	1	175,942	$168,160
Kentucky...	....	....	....	1	....	....	1	....	....
Maryland....	1	....	....	1	....	....	1	....	....
New Jersey..	1	....	....	1	....	....	1	54,161	60,478
New York...	....	....	....	....	....	....	1	....	....
Ohio........	2	115,368	85,249	2	276,211	191,998	2	251,121	184,283
Pennsylvania	1	....	....	1	....	....	1	....	....
Total...	8	303,045	226,651	9	382,447	272,614	10	481,224	412,921

* Taken from "Mineral Resources of the United States," for 1906.

TABLE F.*

The following table shows the imports of all hydraulic cements into the United States, by countries, from 1903 to 1906:

Hydraulic cement is recorded in the custom-houses in pounds

TABLE F.*

IMPORTS, IN BARRELS, OF HYDRAULIC CEMENTS INTO THE UNITED STATES IN 1903-1906, BY COUNTRIES.

	1903	1904	1905	1906
United Kingdom......................	146,994	16,365	33,978	464,940
Belgium.............................	737,576	394,368	335,154	563,590
France..............................	14,866	34,912	18,864	64,227
Germany.............................	1,377,414	585,563	456,325	871,579
Other European countries............	27,415	7,538	602	49,770
British North America...............	4,421	566	417	9,589
Other countries.....................	9,265	7,091	1,237	182,015
Total........................	2,317,951	1,046,403	846,577	2,205,710

* Taken from "Mineral Resources of the United States," for 1906.

when brought into this country from foreign places. Reduced to barrels, the total quantity imported in 1906 was 2,205,710, valued at $2,950,268. The total quantity withdrawn for consumption in 1906 was 2,274,677 barrels.

TABLE G.*

The following table is designed to show the yearly increase in the production of Portland cement in the United States, the fluctuations in natural cement, and the variations in imports for consumption of hydraulic cements into this country since 1901.

The puzzolan-cement production, which is not included in this table, and which has been recorded in government reports only since 1901, is as follows: 1901, 272,689 barrels; 1902, 478,555 barrels; 1903, 525,896 barrels; 1904, 303,045 barrels; 1905, 382,447 barrels; 1906, 481,224 barrels.

TABLE G.*

COMPARISON OF PRODUCTION OF PORTLAND AND NATURAL-ROCK CEMENT, IN BARRELS, IN THE UNITED STATES WITH IMPORTS FOR CONSUMPTION OF HYDRAULIC CEMENT, 1901-1906.

Year	Natural cement	Portland cement	Total of natural and Portland cement	Imports
1901	7,084,823	12,711,225	19,796,048	922,426
1902	8,044,305	17,230,644	25,274,949	1,963,023
1903	7,030,271	22,342,973	29,373,244	2,251,969
1904	4,866,331	26,505,881	31,372,212	968,410
1905	4,473,049	35,246,812	39,719,861	896,845
1906	4,055,797	46,463,424	50,519,221	2,274,677

* Taken from "Mineral Resources of the United States," for 1906.

TABLE H.*

In the following table it is impossible to make comparison between domestic Portland cement and imported Portland cement, for the reason that the figures showing the imports or exports of cement to or from this country are not divided into classes, such as Portland, natural, or puzzolan cements, but are received at the Bureau of Statistics grouped under the general head of "hydraulic cements." Hence the table shows a comparative statement of the production of Portland cement in the United States with the entire quantity of hydraulic cement imported into and consumed in the United States, in 1891, 1904, 1905 and 1906.

The apparent decrease in the percentage of production to consumption in the United States in 1906 is explained by the fact that notwithstanding the greatly increased output of Portland cement, the demand exceeded the supply. On the western coast this deficit was most sharply felt, but it was a factor in nearly every State in the Union in 1906, and in many places during the early part of the year building operations involving the use of large quantities of cement had to be suspended pending the arrival of that material from some other than the local market.

The result of this shortage was an unusual and pronounced

TABLE H.*

COMPARISON OF DOMESTIC PRODUCTION OF PORTLAND CEMENT WITH CONSUMPTION OF PORTLAND AND ALL IMPORTED HYDRAULIC CEMENTS, 1891, 1904, 1905 AND 1906, IN BARRELS.

	1891	1904	1905	1906
Production of Portland Cement in the United States	454,813	26,505,881	35,246,812	46,463,424
Imports (entered for consumption)	2,988,313	968,409	896,845	2,274,677
Total	3,443,126	27,474,290	36,143,657	48,738,101
Exports (domestic)	....	774,940	897,686	583,299
Consumption	3,443,126	26,699,350	35,245,971	48,154,802
Percentage of production of Portland cement to consumption in the United States	13.2	99.2	100	96.49

* Taken from "Mineral Resources of the United States," for 1906.

increase in the quantity of cement sent to this country from abroad during the latter portion of 1906.

This increase is very clearly shown in the figures furnished by the Bureau of Statistics.

TABLE I.*

The following table shows exports of hydraulic cements since 1900.

The fact that in 1906 the quantity of cement exported from this country amounted to but little more than 500,000 barrels, or but a trifle over half as much as was exported during the preceding year, marks the fact that the supply of cement in the United States in 1906 was not equal to the demand.

The total quantity of hydraulic cement exported from the United States in 1906 was 583,299 barrels, valued at $944,886; decidedly less than the quantity exported in 1904 or 1905:

TABLE I.*

EXPORTS OF HYDRAULIC CEMENT, 1900-1906, IN BARRELS.

Year	Quantity	Value	Year	Quantity	Value
1900	100,400	$225,306	1904	774,940	$1,104,086
1901	373,934	679,296	1905	897,686	1,387,906
1902	340,821	526,471	1906	583,299	944,886
1903	285,463	433,984			

* Taken from "Mineral Resources of the United States," for 1906.

TABLE J.*

The following table shows the apparent total consumption in the United States of all hydraulic cements in 1906:

TABLE J.*

TOTAL CONSUMPTION OF HYDRAULIC CEMENTS IN 1906, IN BARRELS.

Total production in United States	51,000,445
Imports withdrawn for consumption	2,274,677
Total	53,275,122
Exports	583,299
Total consumption	52,691,823

* Taken from "Mineral Resources of the United States," for 1906.

TABLE K.*

The following table shows the value of the various kinds of stone produced in 1905 and 1906, by States and Territories:

TABLE K.*

VALUE OF VARIOUS KINDS OF STONE PRODUCED IN 1905 AND 1906, BY STATES AND TERRITORIES.

1905

State or Territory	Granite	Sandstone	Marble	Limestone	Total value
Alabama	....	$28,107	....	$532,103	$560,210
Alaska	....	....	$710	....	710
Arizona	$3,700	65,558	....	135	69,393
Arkansas	90,312	58,161	1,000	154,818	304,291
California	1,700,818	685,668	95,540	49,902	2,531,928
Colorado	73,802	453,029	....	289,920	816,751
Connecticut	949,888	62,618	....	1,558	1,014,064
Delaware	178,428	....	....	....	178,428
Florida	....	....	....	5,800	5,800
Georgia	971,207	....	774,550	9,030	1,754,787
Hawaii	33,550	....	....	....	33,550
Idaho	1,500	22,265	....	14,105	37,870
Illinois	....	29,115	....	3,511,890	3,541,005
Indiana	....	15,421	....	3,189,259	3,204,680
Indian Territory	1,800	2,198	....	5,512	9,510
Iowa	....	9,335	....	451,791	461,126
Kansas	....	79,617	....	923,389	1,003,006
Kentucky	....	280,579	....	744,465	1,025,044
Maine	2,713,795	....	....	7,428	2,721,223
Maryland	957,048	12,984	138,404	149,402	1,257,838
Massachusetts	2,663,329	367,461	166,360	65,908	3,263,058
Michigan	....	123,123	....	544,754	667,877
Minnesota	481,908	294,640	....	555,401	1,331,949
Missouri	180,579	27,686	....	2,238,164	2,446,429
Montana	126,430	45,116	....	103,123	274,669
Nebraska	....	120	....	225,119	225,239
Nevada	....	1,500	....	....	1,500
New Hampshire	838,371	....	....	....	838,371
New Jersey	834,709	294,719	....	147,353	1,276,781
New Mexico	....	101,522	2,200	7,200	110,922
New York	765,777	*a*1,831,756	795,721	1,970,968	5,364,222
North Carolina	564,578	4,483	....	16,500	585,561
North Dakota	....	1,055	....	....	1,055
Ohio	....	1,744,472	....	2,850,793	4,595,265
Oklahoma	18,920	12,914	....	163,412	195,246
Oregon	85,330	1,229	....	8,600	95,159
Pennsylvania	870,848	*a*2,487,939	97,887	4,499,503	7,956,177
Rhode Island	556,364	....	....	300	556,664
South Carolina	297,284	....	....	....	297,284
South Dakota	....	193,408	....	6,653	200,061
Tennessee	....	8,715	582,229	401,622	992,566
Texas	132,193	123,281	....	171,847	427,321
Utah	13,630	43,429	1,150	232,519	290,728
Vermont	2,571,850	....	4,410,820	11,095	6,993,765
Virginia	452,390	2,000	....	212,660	667,050
Washington	681,730	124,910	60,000	52,470	919,110
West Virginia	....	171,309	....	671,318	842,627
Wisconsin	825,625	161,741	....	804,081	1,791,447
Wyoming	....	33,591	2,500	23,340	59,431
Total	*b*20,637,693	*a*10,006,774	7,129,071	26,025,210	63,798,748

a Includes bluestone. *b* Includes trap and other igneous rocks.

* Taken from "Mineral Resources of the United States," for 1906.

TABLE K. (*Continued.*)

Value of Various Kinds of Stone Produced in 1905 and 1906, by States and Territories.

1906

State or Territory	Granite	Sandstone	Marble	Limestone	Total value
Alabama	....	$40,467	$85,000	$579,344	$704,811
Alaska	....	....	(a)	....	(a)
Arizona	$32,042	33,149	....	40	65,231
Arkansas	118,903	55,703	16,900	48,844	240,350
California	1,429,207	642,166	103,048	80,205	2,254,626
Colorado	65,402	286,544	....	373,158	725,104
Connecticut	1,385,369	(b)	....	1,171	1,386,540
Delaware	146.346	....	....	....	146,346
Florida	....	....	....	1,450	1,450
Georgia	792,315	....	919,356	16,042	1,727,713
Hawaii	23,346	....	....	....	23,346
Idaho	400	11,969	....	12,600	24,969
Illinois	....	19,125	....	2,942,331	2,961,456
Indiana	....	30,740	....	3,725,565	3,756,305
Indian Territory	....	615	....	44,622	45,237
Iowa	....	5,601	....	493,815	499,416
Kansas	....	42,809	....	849,203	892,012
Kentucky	....	125,123	....	795,408	920,531
Maine	2,560,021	....	....	2,000	2,562,021
Maryland	883,881	9,533	176,495	170,046	1,239,955
Massachusetts	3,790,211	260,721	271,934	10,750	4,333,615
Michigan	....	65,395	....	656,269	721,664
Minnesota	626,069	285,633	....	632,115	1,543,817
Missouri	150,009	20,951	(c)	1,988,334	2,159,294
Montana	114,005	37,462	....	141,082	292,549
Nebraska	....	6,899	....	276,381	283,280
Nevada	....	....	5,000	....	5,000
New Hampshire	818,131	....	....	....	818,131
New Jersey	958,110	215,142	....	221,141	1,394,393
New Mexico	....	42,574	500	125,493	168,567
New York	927,483	*de*1,905,892	557,954	2,204,724	5,596,053
North Carolina	778,847	3,531	....	30,583	812,961
North Dakota	....	44	....	....	44
Ohio	....	1,426,645	....	3,025,038	4,451,683
Oklahoma	18,847	40,246	....	127,361	186,454
Oregon	58,961	25,950	....	7,480	92,391
Pennsylvania	1,043,140	*d*2,724,874	171,632	4,865,130	8,804,776
Rhode Island	622,812	....	....	678	623,490
South Carolina	247,998	....	....	10,400	258,398
South Dakota	....	145,966	....	....	145,966
Tennessee	....	14,136	635,821	481,952	1,131,909
Texas	168,061	111,533	....	239,125	518,719
Utah	4,948	37,529	1,400	248,868	292,745
Vermont	2,941,724	....	4,576,913	7,829	7,526,466
Virginia	340,900	5,100	....	260,343	606,343
Washington	459,975	169,500	59,985	49,192	738,652
West Virginia	....	113,369	....	628,602	741,971
Wisconsin	798,213	181,986	....	891,746	1,871,945
Wyoming	600	24,715	1,000	53,783	80,098
Total	*f*22,306,276	9,169,337	7,582,938	27,320,243	66,378,794

a Included with Washington.
b Included with New York.
c Included in limestone.
d Includes bluestone.
e Includes a small output for Connecticut.
f Includes trap rock and other igneous rocks

TABLE L.*

The following table shows the rank of the States and Territories in 1905 and 1906, according to value of production of stone, and the percentage of the total stone produced by each State or Territory:

TABLE L.*

RANK OF STATES AND TERRITORIES IN 1905 AND 1906, ACCORDING TO VALUE OF PRODUCTION OF STONE, AND PERCENTAGE OF TOTAL STONE PRODUCED BY EACH STATE AND TERRITORY.

1905				1906			
Rank of State	State or Territory	Total value	Percentage of total	Rank of State	State or Territory	Total value	Percentage of total
1	Pennsylvania....	$7,956,177	12.47	1	Pennsylvania.....	$8,804,776	13.27
2	Vermont........	6,993,765	10.96	2	Vermont.........	7,526,466	11.34
3	New York.......	5,364,222	8.41	3	New York*a*......	5,596,053	8.43
4	Ohio............	4,595,265	7.20	4	Ohio............	4,451,683	6.71
5	Illinois..........	3,541,005	5.55	5	Massachusetts....	4,333,616	6.53
6	Massachusetts...	3,263,058	5.11	6	Indiana.........	3,756,305	5.66
7	Indiana.........	3,204,680	5.02	7	Illinois..........	2,961,456	4.46
8	Maine..........	2,721,223	4.27	8	Maine..........	2,562,021	3.86
9	California.......	2,531,928	3.97	9	California........	2,254,626	3.40
10	Missouri.........	2,446,429	3.83	10	Missouri.........	2,159,294	3.25
11	Wisconsin.......	1,791,447	2.81	11	Wisconsin........	1,871,945	2.82
12	Georgia.........	1,754,787	2.75	12	Georgia..........	1,727,713	2.60
13	Minnesota.......	1,331,949	2.09	13	Minnesota.......	1,543,817	2.33
14	New Jersey......	1,276,781	2.00	14	New Jersey......	1,394,393	2.10
15	Maryland........	1,257,838	1.97	15	Connecticut......	1,386,540	2.09
16	Kentucky.......	1,025,044	1.61	16	Maryland........	1,239,955	1.87
17	Connecticut.....	1,014,064	1.59	17	Tennessee........	1,131,909	1.71
18	Kansas..........	1,003,006	1.57	18	Kentucky........	920,531	1.39
19	Tennessee.......	992,566	1.56	19	Kansas..........	892,012	1.34
20	Washington.....	919,110	1.44	20	New Hampshire..	818,131	1.23
21	West Virginia....	842,627	1.32	21	North Carolina...	812,961	1.23
22	New Hampshire..	838,371	1.31	22	West Virginia....	741,971	1.12
23	Colorado........	816,751	1.28	23	Washington*b*.....	738,652	1.11
24	Michigan........	667,877	1.05	24	Colorado.........	725,104	1.09
25	Virginia.........	667,050	1.05	25	Michigan........	721,664	1.09
26	North Carolina...	585,561	.92	26	Alabama.........	704,811	1.06
27	Alabama........	560,210	.88	27	Rhode Island....	623,490	.94
28	Rhode Island....	556,664	.87	28	Virginia.........	606,343	.91
29	Iowa............	461,126	.72	29	Texas...........	518,719	.78
30	Texas...........	427,321	.67	30	Iowa............	499,416	.75
31	Arkansas........	304,291	.48	31	Utah	292,745	.44
32	South Carolina...	297,284	.47	32	Montana.........	292,549	.44
33	Utah............	290,728	.46	33	Nebraska........	283,280	.43
34	Montana........	274,669	.43	34	South Carolina...	258,398	.39
35	Nebraska........	225,239	.35	35	Arkansas........	240,350	.36
36	South Dakota...	200,061	.31	36	Oklahoma.......	186,454	.28
37	Oklahoma.......	195,246	.31	37	New Mexico......	168,567	.25
38	Delaware........	178,428	.28	38	Delaware........	146,346	.22
39	New Mexico.....	110,922	.17	39	South Dakota....	145,966	.22
40	Oregon..........	95,159	.15	40	Oregon..........	92,391	.13
41	Arizona.........	69,393	.11	41	Wyoming........	80,098	.12
42	Wyoming.......	59,431		42	Arizona..........	65,231	.10
43	Idaho...........	37,870		43	Indian Territory..	45,237	
44	Hawaii..........	33,550		44	Idaho...........	24,969	
45	Indian Territory.	9,510	.23	45	Hawaii..........	23,346	.15
46	Florida..........	5,800		46	Nevada..........	5,000	
47	Nevada.........	1,500		47	Florida..........	1,450	
48	North Dakota...	1,055		48	North Dakota....	44	
49	Alaska..........	710					
	Total.......	63,798,748	100.00		Total.......	66,378,794	100.00

a Includes a small output of sandstone from Connecticut. *b* Includes Alaska marble.

* Taken from "Mineral Resources of the United States," for 1906.

The four following tables, M, N, O and P, with the addenda relating to the properties and chemical composition of building stones and to stone buildings, have been compiled by the author from various sources (principally from several volumes of *Stone* and from Merrill's "Stones for Building and Decoration"), and are believed to be reliable:

TABLE M.§

SHOWING THE WEIGHT, CRUSHING STRENGTH AND RATIO OF ABSORPTION OF VARIOUS BUILDING STONES.

Kind of Stone.	Locality.	Approximate size of cube in inches.	Position.	Strength per square inch.	Weight per cubic foot.	Ratio of Absorption.
Granite (Biotite)........	Vinalhaven, Me........	2	Bed	15,698	163	....
"	Dix Island, Me........	2	....	15,000*	166.5	....
"	Hurricane Island, Me...	2	Bed	14,425*	166.9	....
"	" " ...	2	Edge	14,937*	166.9	....
"	Fox Island, Me........	2	....	14,875*	164.1	....
"	Keene, N. H..........	2	Bed	10,375	166	1/800
Granite (Hornblende)...	Cape Ann, Mass........	2	Bed	12,423*	......	....
" ...	" "	2	Bed	19,500*	......	....
...	Rockport, Mass........	2	Bed Edge	16,300 19,750	163.2	1/158
" ...	Quincy, Mass..........	2	....	17,750†	166.2	....
" ...	"	2	....	14,750†	168.7	....
Granite (Biotite)........	Milford, Conn.........	6	....	22,610	......	....
"	Westerly, R. I.........	2	....	17,500	165.6	....
"	"	2	Edge	14,937*	166.9	....
"	Huron Island, Mich....	2	Bed	18,125	164.4	1/658
"	" "	2	Edge	14,425	163.7	1/368
Granite (Hornblende)...	East Saint Cloud, Minn.	2	Bed Edge	28,000 26,250	168.2	....
" ...	Saint Cloud, Minn.....	2	Bed Edge	16,000 18,500	168.2	1/389
Granite (Gabbro).......	Duluth, Minn..........	2	Bed	17,631	175	....
Granite (Biotite)........	Tarrytown, N. Y.......	2	Bed	18,250†	162.2	....
"	Staten Island, N. Y....	2	Bed	22,250†	178.8	....
"	Gunnison, Colo........	2	Bed Edge	12,976 15,594	169.4	....
"	Platte Canon, Colo.....	2	Bed Edge	14,585 14,634	163.8	....
Limestone (Dolomite)...	Joliet, Ill..............	2	Bed	14,775*	160	1/94
" ...	Lemont, Ill............	2	Bed	12,000*	165.3	1/89
" ...	Quincy, Ill............	2	Bed	9,687*	160.6	1/180
Limestone (Oolitic).....	Bedford, Ind..........	..	....	6,500	147	1/24
"	"	..	....	10,125	152.4	1/33
"	" (buff)	..	....	14,000‡	......	....
"	Salem, Ind............	..	....	8,625	144.3	1/28
Limestone (Dolomite)...	Stillwater, Minn........	2	Bed Edge	25,000 25,000	172.6	1/261
" ...	"	2	Bed Edge	10,750 12,750	160.4	1/40

* Burst suddenly. † Cracked before bursting.

‡ Tests made at U. S. Arsenal, Watertown, Mass. § See also Addenda to this Table.

Consult also Art. 229, Chap. V., for a list of some recent publications on building stones, in which the various properties of other stones are given.

TABLE M (*Continued.*)

Kind of Stone.	Locality.	Approximate size of cube in inches.	Position.	Strength per square inch.	Weight per cubic foot.	Ratio of Absorption.
Limestone (Dolomite)...	Red Wing, Minn.......	2	Bed Edge	23,000 23,250	162.2	$\frac{1}{40}$
Limestone (Magnesian)..	Glens Falls, N. Y......	2	Bed Edge	11,475* 10,750	168.8	....
" ..	Lake Champlain, N. Y.	2	Bed Edge	25,000* 21,500	171.9	....
Marble (Dolomite)......	Lee, Mass.............	6	Bed	22,900	......	....
"	Centre Rutland, Vt.....	6 ‡	....	10,746	166.6	....
"	Dorset, Vt.............	2	Edge	8,670	167.8	....
"	"Cherokee," Georgia...	6	....	10,976	......	....
"	" ...	4 ‡	....	13,415	......	....
"	" ...	4 ‡	....	11,822	......	....
"	"Creole," Georgia.....	6	....	12,078	......	....
"	"	4 ‡	....	11,420	......	....
"	"	4 ‡	....	15,512	......	....
"	"Etowah," Georgia....	6	....	10,642	......	....
"	"	4 ‡	....	14,217	......	....
"	"	4 ‡	....	13,888	......	....
"	"Kennesaw," Georgia..	4 ‡	....	8,354	......	....
"	" ..	4 ‡	....	10,771	......	....
Marble (Pink)..........	East Tennessee.........	2	....	15,750	......	$\frac{1}{1220}$
Marble (White)........	"	2	....	17,212	......	$\frac{1}{1240}$
"	"	2	....	14,812	......	$\frac{1}{1480}$
Marble (Dark Pink).....	"	1	....	13,750	......	$\frac{1}{1070}$
Sandstone (Brownstone).	Portland, Conn.........	$2\frac{1}{2}$‡	....	13,980	......	....
" ..	"	$2\frac{1}{2}$‡	....	13,330	......	....
" ..	"	3 ‡	....	13,920	......	....
" ..	"	3 ‡	....	15,020	......	....
" ..	"	$2\frac{1}{2}$‡	....	9,900	......	....
" ..	Cromwell, Conn........	$2\frac{1}{2}$‡	Bed	12,250	Average of 6 tests	
Sandstone (Con.)						
" Brown (soft)..	East Longmeadow, Mass	4 ‡	....	8,437	......	....
" " (hard).	" "	4 ‡	....	14,085	......	....
" (Kibbe)......	" "	6 ‡	....	12,619	......	....
" "	Potsdam, N. Y.........	2 ‡	....	18,401	......	....
" "	"	2 ‡	....	42,000	......	....
" (lilac color)...	Medina, N. Y.........	2	Bed	17,250	150.6	$\frac{1}{55}$
" (light).......	North Amherst, Ohio...	2	Edge	5,450	133.7	$\frac{1}{19}$
" "	" " ...	2	Bed	6,212	135.8	$\frac{1}{19}$
" "	Berea, Ohio............	6	Bed	6,510	......	....
" "	"	2	Bed	8,222	134	$\frac{1}{21}$
" "	Cleveland, Ohio........	2	Bed	6,800	140	$\frac{1}{37}$
" "	Hummelstown, Pa......	6	Bed	12,810	......	....
" "	Fond du Lac, Wis......	2	Bed	6,237	138.8	$\frac{1}{22}$
" (hard, red)...	Saint Vrains, Colo......	2	Bed	11,505	149.3*	.061
" (hard, gray)..	Fort Collins, Colo......	2	Bed	11,707	140.7	.072
" " ..	Stout, Colo............	2	Bed	10,514	141.2	.066
" (light red)....	Manitou, Colo.........	2 ‡	Bed	11,000	140	....
" "	"	2	Bed	6,000	......	....

SLATE.

Locality.	Modulus of Rupture.	Weight per cubic foot.	Porosity.	Corrodibility.
Albion, Penn..................	7,150 lbs.	173.2	0.238	0.547
Old Bangor, Penn.............	9,810 "	173.5	0.145	0.446
Peach bottom region, Penn.....	11,260 "	180.4	0.224	0.226

* Burst suddenly. † Cracked before bursting.
‡ Tests made at U. S. Arsenal, Watertown, Mass.

ADDENDA* FOR TABLE M.

Table Showing the Specific Gravity, Strength Per Square Inch, Etc.

Kind of Stone	Locality	Size of Cube, in inches	Position	Strength per sq. inch	Specific gravity	Weight per cub. foot	Ratio of absorption	Remarks	Authority
Syenite ("Blue Granite")	Fourche Mt., Ark.	1.47		26,000	2.65	166.		Av. of 5 det's.	1
Syenite ("Gray Granite")	do.	1.42		14,000	2.56	159.8			1
Granodiorite (Granite)	Rocklin, Cal.	3.96 x 3.96 x 3.96		21,817					2
Granite	Lithonia, Ga.	2.02 x 2.02 x 2.08		18,017					3
do.	Stone Mt., Ga.	2.04 x 2.07 x 2.05		13,190	2.686	167.9			3
do.	Hurricane Is., Me.	2.017 x 2.018 x 2.022		19,583					4
do.	Jonesboro, Me.	2.01 x 2.016 x 2.013		24,507					4
do.	Waldoboro, Me.	2.01 x 2.013 x 2.012		23,111					4
do.	Port Deposit, Md.	2		21,180	2.72	170.			5
do.	Woodstock, Md.			21,140					
do.	Cape Ann, Mass.	6 x 4 x 11.93		20,296					2
do.	Milford, Mass.	4.06 x 4 x 4.08		30,888					2
do.	Barre, Vt.	2 x 2.06 x 2.04		19,957	2.67	166.87	1/121		6
do.	Richmond, Va.			25,520					7
do.	Athelstone, Wis.	2		20,145	2.70	167.95			8
do.	Montello, Wis.	2		13,639		164.33			8
Limestone (Marble)	Pickens Co., Ga.	1	Bed.	11,036	2.717	169.8		Av. of 2 det's.	9
do.	do.	1	do.	13,400	2.763	172.6		Av. of 3 det's.	9
Dolomite (Marble)	Lee, Mass.	11.99 x 5.88 x 3.98		18,047					2
do.	Dover, N. Y.	1.995 x 2.01 x 2.01		18,836					2
Magnesian Limestone	Gouverneur, N. Y.	6.11 x 6.11 x 6.28		12,692					2
Sandstone	Chuckanut Bay, Wash.	4.09 x 4.13 x 4.20		12,790					2

1. J. F. Williams, Ann. Rep. Geol. Survey of Ark., Vol. II, 1891.
2. Watertown Arsenal.
3. J. P. Claypole.
4. I. H. Woolson, School of Mines, Columbia College, N. Y.
5. Building and Decorative Stones of Md., p. 145.
6. 20th Ann. Rep. U. S. Geol. Survey, Part 6, p. 447.
7. Hunt & Clapp, Pittsburg, Pa.
8. E. B. Buckley, Building and Ornamental Stones of Wis.
9. Prelim. Rep. on Marbles of Ga.

* Taken by permission from 1903 edition of "Stones for Building and Decoration," by George P. Merrill.

TABLE N.*

Showing the Chemical Composition of Various Building Stones.†

GRANITES.

Description.	Locality.	Silica.	Alumina.	Iron Oxides.	Lime.	Potash and Soda.
Light.............	Monson, Mass..........	73.47	15.07	1.15	4.48	5.97
Dark..............	"	69.35	18.83	2.00	5.94	3.78
Hornblende........	East Saint Cloud, Minn.	65.12	16.96	4.69	4.77	5.25
"	" " ..	74.43	12.68	3.82	1.28	3.88
Diabose...........	Duluth, Minn..........	50.43	23.83	17.63	4.79	2.40
Gabbro............	"	48.51	13.79	19.34	8.34	1.86

SANDSTONES.

Description.	Locality.	Silica.	Alumina.	Iron Oxides.	Lime.	Water and Loss.
Maynard (red)......	E. Longmeadow, Mass..	79.38	8.75	2.43	2.57	2.79
Worcester (red).....	" " ..	88.89	5.95	1.79	.27	1.83
Kibbe quartz......	" " ..	81.38	9.44	3.54	.76	4.49
Brownstone........	Portland, Conn.........	69.94	13.15	2.48	3.09	1.01
"	"	70.11	13.49	4.85	2.39	7.37‡
Sandstone..........	Stony Point, Mich......	84.57	5.90	6.48	....	1.92
Portage Entry (red).	Lake Superior, Mich....	94.73	0.36	2.64	0.69	.83
Quartzite..........	Pipestone, Minn........	84.52	12.33	2.12	0.31	2.31
Buff..............	Amherst, Ohio.........	97.00	.....	1.00	1.15	.21
Berea.............	Berea, Ohio............	96.90	.....	1.68	.55	.32
Euclid Bluestone...	Euclid County, Ohio....	95.00	2.50	1.00	....	1.50
Columbia..........	Columbia, Ohio........	96.50	.....	....	....	2.00
Red..............	Laurel Run, Pa........	94.00	.....	1.90	1.10	1.92
Elyria............	Grafton, Ohio..........	87.66	1.72	3.52	.17	2.03
Sandstone.........	Fond du Lac, Minn....	78.24	10.88	3.83	.95	....
"	Flagstaff, Arizona......	79.19	3.75		7.76	3.26
"	Dorchester, N. Brunsw'k	82.52	7.07	3.55	1.83	3.61

† Some minor elements occurring in very small quantities and not affecting the durability of the stone are omitted. ‡ Potash and soda.

* See also Art. 229, Chap. V., for a list of some recent publications on building stones, in which the chemical composition of other stones are given.

TABLE N (*Continued.*)

LIMESTONES OTHER THAN MARBLES.

Description.	Locality.	Carbonate of Lime.	Carbonate of Magnesia.	Oxides of Iron.	Oxide of Aluminum.	Silica and insoluble residue.	Water and Loss.
Dolomite	Lemont, Ill.	45.80	......	2.30	7.00	15.90	6.90
Oolitic	Bedford, Ind.	96.60	0.13	0.98		0.50	0.96
"	"	97.26	0.37	0.49	....	1.69	0.19
" (buff)	"	98.20	0.39	0.39	....	0.63	.....
" (blue)	"	97.26	0.37	0.49	....	1.69	.....
"	Spencer, Ind.	96.80	0.11	0.91	....	0.70	0.92
Oolitic	Bowling Green, Ky.	95.31	1.12	0.39	....	1.42	1.76
Dolomite	Minneapolis, Minn	54.53	36	0.90	3.16	16.22	0.375
"	"	41.88	24.55	4.03	....	29.93	.....
"	"	75.48	6.81	1.70	....	14.45	1.60
"	Kasota, Minn.	49.16	37.53	1.09	....	13.06	.....
"	Stillwater, Minn.	50.22	37.39	0.78	0.64	8.54	.....
"	Frontenac, Minn.	54.78	42.53	0.36	0.31	2.93	.....
Limestone	Dayton, Ohio	92.40	1.10	0.58	....	1.70	1.08
Dolomite	Springfield, Ohio	54.70	44.93	0.20	....	0.10	.....
Limestone (Caen)	Aubigney, France	97.60	......	....	....	1.70	.....
" (Oolitic)	Portland, England	95.16	1.20	0.50	....	1.20	1.94

MARBLES.

Description.	Locality.	Carbonate of Lime.	Carbonate of Magnesia.	Oxides of Iron and Aluminum.	Insoluble Residue.
Dolomite	Hastings, N. Y.	52.82	45.78	....	....
" (white)	Sing Sing, N. Y.	53.24	45.89	....	....
"	Tuckahoe, N. Y.	61.75	38.25	....	....
" (white)	Pleasantville, N. Y.	54.62	45.04	0.23	....
" "	Lee, Mass.	54.62	43.93	.365	....
Limestone (white)	Rutland, Vt.	97.73	.....	.59	1.68
" (greenish)	"	85.45	.....	14.55	....
" (white)	West Rutland, Vt.	98.00	.....	....	0.57
" (bluish gray)	Proctor, Vt.	98.37	0.79	0.005	0.63
" (light colored)	"	96.30	3.06	....	0.63
"	East Tennessee	98.78	0.67	0.26	.08
Georgia Marble Co.	Georgia	97.32	1.60	.26	....
Southern Marble Co.	"	98.96	0.13	.22	....
" "	"	98.52	0.88	....	....
Carrara (white)	Italy	99.24	0.28	....	....
"	"	98.76	0.9	1.08	0.16

TABLE N (*Continued.*)

ONYX MARBLES.

Source.	Color.	Weight per cubic foot.	Carbonate of Lime.	Carbonate of Magnesia.	Carbonate of Iron.
Hacienda del Carmen, Mexico.....	Light green..........	171.87	89.36	3.00	5.24
Mayer's Station, Arizona..........	"	171.87	93.93	0.56	5.50
" "	Red brown..........	166.87	93.82	0.53	4.06
Cave Creek, Arizona..............	Light green..........	171.87	93.48	1.07	5.19
Suisin City, California............	Dark amber..........	170.62	95.48	2.20	....
Sulphur Creek, "	"	167.5	.....	....	....
San Luis Obispo, California........	White...............	170	93.68	1.43	3.93
Rio Puerco, Valencia County, New Mexico......................	Light green..........	179.37	.....	....	....
New Pedrara, Lower California....	Faintly green........	174.37	90.16	1.66	6.97
" "	White, rose tinted....	173	93.48	1.68	4.19
" "	White...............	174	96.86	0.24	2.79
" "	Faintly green........	174.37	91.09	0.64	7.49
Near Lehi, Utah.................	Yellow.............	170	97.61	0.23	....

SLATES.

Source.	Silica.*	Alumina.*	Protoxide of Iron.*	Peroxide of Iron.*	Magnesia.	Alkalies.
Rutland County, Vt. (sea green)........	65.02	16.02	5.44	2.99	2.00	4.16
" (unfading green)...	64.71	7.84	5.44	7.23	1.63	6.92
" (purple)..........	62.37	13.40	4.21	7.66	0.90	7.20
Granville, N. Y. (red).................	73.97	5.16	1.74	10.17	1.43	3.92
Old Bangor, Penn. (dark)..............	56.97		26.05		2.69	2.31
Albion, Penn. (dark)...................	55.18	....	25.57	carbon	2.10	4.00
Peach Bottom Region, Penn. (dark).....	58.37	21.98	10.66	0.93	1.20	1.93

* These are the valuable constituents. "Peroxide of iron is probably the coloring matter."

TABLE O.*

List of Important Stone Buildings in the United States.

GRANITE BUILDINGS.†

Locality of Quarries.	Name of Building.	City.
Dix Island, Me	Post Office	New York City.
"	(New) Post Office	Philadelphia, Pa.
Hallowell, Me	State Capitol	Albany, N. Y.
"	State Capitol	Augusta, Me.
"	Equitable Insurance Co. Building	Boston, Mass.
Cape Ann, Mass	Post Office	"
Milford, Mass	City Hall	Albany, N. Y.
Quincy, Mass	U. S. Custom House	Boston, Mass.
"	Bunker Hill Monument	Charlestown, Mass.
"	Post Office	Providence, R. I.
"	Astor House	New York City.
"	Philadelphia National Bank	Philadelphia.
"	Presbyterian Church	Savannah, Ga.
"	U. S. Custom House	Mobile, Ala.
"	U. S. Custom House	New Orleans, La.
Concord, N. H	Congressional Library	Washington, D. C.
"	State Capitol	Concord, N. H.
Gunnison, Colo	State Capitol	Denver, Colo.
Little Cottonwood Canon, Utah	Mormon Assembly House and Temple	Salt Lake City, Utah.

LIMESTONE BUILDINGS.‡

Locality of Quarries.	Name of Building.	City.
Lockport, N. Y	Lenox Library	New York City.
Bedford, Ind	Algonquin Club Building	Boston, Mass.
"	Residence of Mr. Robert Goelet	Newport, R. I.
"	Manhattan Life Insurance Building	New York City.
"	Mail and Express Building	"
"	American Fine Arts Society Building	"
"	Residences of Cornelius Vanderbilt and W. K. Vanderbilt	" (Fifth Avenue).
"	Manufacturers' Club Building	Philadelphia, Pa.
"	Tioga Baptist Church	"
"	State Capitol	Indianapolis, Ind.
"	Auditorium Building	Chicago, Ill.
"	Union Station	St. Louis, Mo.
"	Cotton Exchange Building	New Orleans, La.
"	Biltmore	Biltmore, N. C.
Lemont, Ill	St. Paul Universalist Church	Chicago, Ill.
"	Central Music Hall	"
St. Paul, Minn	Catholic Cathedral	St. Paul, Minn.
Kaosta, Minn	Post Office	"
Bowling Green, Ky	U. S. Custom House	Nashville, Tenn.

* See also Addenda to this Table. This table and the addenda are given as a guide to architects in judging of the appearance and weathering properties of different stones. Some of these stones are used in a great many other buildings in the cities mentioned, the idea of the author being to give only one or two examples in each city.

† See also Chap. V., Art. 230, for new classified lists of buildings recently erected, in which various kinds of granite are used.

‡ See also Chap. V., Art. 232, for new lists.

TABLE O (*Continued.*)

MARBLE BUILDINGS.*

Locality of Quarries.	Name of Building.	City.
Rutland, Vt.	(Old) Parker House, on School Street	Boston, Mass.
Lee, Mass.	St. Patrick's Cathedral (in part)	New York City.
"	New City Buildings	Philadelphia, Pa.
"	Washington Monument (in part)	Washington, D. C.
"	U. S. Capitol Extension	"
Tuckahoe, N. Y.	New York Life Insurance Building	Boston, Mass.
"	Hotel Vendome (new part)	"
Montgomery County, Pa.	Girard College	Philadelphia, Pa.
East Tennessee	Blackstone Memorial Library	Branford, Conn.
"	U. S. Custom House and Post Office	Knoxville, Tenn.
"	U. S. Custom House and Post Office	Memphis, Tenn.
"	U. S. Custom House and Post Office	Chattanooga, Tenn.
Georgia	Trimmings, Ames Building	Boston, Mass.
"	St. John's Episcopal Church	Knoxville, Tenn.
"	Grand Opera House	Atlanta, Ga.
"	U. S. Custom House and Post Office	Jacksonville, Fla.

SANDSTONE BUILDINGS.†

Locality of Quarries.	Name of Building.	City.
Longmeadow, Mass. (red stone)	Trimmings, Trinity Church	Boston, Mass.
Longmeadow, Mass. (red stone)	Union League Club House	Chicago, Ill.
Portland, Conn. (brownstone)	Technology (original) Building	Boston, Mass.
" "	Alumni Hall, Library and Art School, Yale College	Hartford, Conn.
" "	Residences of Wm. H. Vanderbilt and Messrs. Twombly and Webb	New York City (Fifth Avenue).
" "	Astor Library	New York City.
" "	Academy of Design (Montague Street)	Brooklyn, N. Y.
" "	Music Hall	Buffalo, N. Y.
" "	Union League Club Building	Philadelphia, Pa
" "	Residence of Geo. H. Pullman	Chicago, Ill.
" "	Savings Bank of Baltimore	Baltimore, Md.
Potsdam, N. Y. (red stone)	Parliament Buildings	Ottawa, Ont.
" "	Columbia College	New York City.
" "	All Saints Cathedral	Albany, N. Y.
Ohio Sandstone (buff stone)	Palmer House	Chicago, Ill.
" "	State Capitol	Lansing, Mich.
Portage Entry, Mich. (red stone)	State Mining School Buildings	Houghton, Mich.
Fond du Lac, Minn. (reddish brown stone)	Westminster Presbyterian Church	Minneapolis, Minn.
Kettle River, Minn.	Board of Trade Building	West Superior, Wis.
Fort Collins, Colo. (dark red stone)	Grace Methodist Church	Denver, Colo.
Fort Collins, Colo. (dark red stone)	Union Pacific Depot	Cheyenne, Wy.
Fort Collins, Colo. (dark red stone)	American Exchange Bank	Kansas City, Mo.
Manitou, Colo. (red stone)	Boston Building	Denver, Colo

* See also Chap. V., Art. 235, for new classified lists of buildings recently erected, in which various kinds of marble are used.

† See also Chap. V., Art. 239, for new lists.

ADDENDA* FOR TABLE O.

List of Some of the More Important Stone Structures of the United States.

LOCALITY	STRUCTURE	MATERIAL
Allegheny, Pa	Post-office	Granite, Hollowell, Me
Ashland, Wis	....do	Sandstone, Prentice Quarry, Houghton, Wis
Astoria, Ore	Custom-house	Sandstone, near Astoria
Baltimore, Md	Court-house and P. O.	Granite, Cape Ann, Mass
Boston, Mass	Tremont building	Granite, Milford, Mass
....do	Chamber of Commerce	....do
....do	Exchange Building	....do...Stony Creek, Conn
....do	S. Union R. R. Station	....do
Bridgeport, Conn	Post-office	Sandstone, Middlesex Co., Conn.
Brooklyn, N. Y	....do	Granite, Vinalhaven, Me
Camden, N. J	Custom-house and P. O.	Marble, Proctor, Vt
Charleston, S. C	Custom-house	Marble, Hastings, N. Y., and Tuckahoe, N. Y
Chicago, Ill	Newberry Library	Granite, Stony Creek, Conn
Cincinnati, Ohio	Chamber of Commerce	Granite, Milford, Mass
Columbus, Ohio	Court-house and P. O.	Sandstone, Berea, Ohio
Dayton, Ohio	Post-office	....do
Des Moines, Ia	Court-house and P. O.	Limestone, Keokuk, Ill., and Joliet, Ill
Detroit, Mich	....do	Limestone, Bedford, Ind
Duluth, Minn	....do	....do
Evansville, Ind	....do	....do
Fort Wayne, Ind	....do	Sandstone, Sand Point, Mich
Frankfort, Ky	....do	Limestone, Bedford, Ind
Jacksonville, Fla	....do	Georgia Marble
Kansas City, Mo	....do	Granite, South Park, Colo., and Llano Co., Tex
Lafayette, Ind	Post-office	Berea Sandstone
Little Rock, Ark	Court-house and P. O.	....do
Lowell, Mass	Post-office	Granite, Deer Island, Me
Madison, Ind	....do	Sandstone, Portage, Mich., and Limestone, Bedford, Ind
Milwaukee, Wis	Court-house, Post-office, and Custom-house	Granite, Frankfort, Me
Minneapolis, Minn	Post-office	Sandstone, Berea, Ohio
New Albany, Ind	Court-house and P. O.	....do
Newark, N. J	Custom-house and P. O.	Sandstone, Belleville, N. J
Newhaven, Conn	Osborn Memorial Hall	Granite, Stony Creek, Conn
New York City	Court-house and P. O.	Granite, Dix Island, Me
....do	Library, Columbia U.	Granite, Stony Creek, Conn., and Milford Mass

* Taken by permission from 1903 edition of "Stones for Building and Decoration," by George P. Merrill.

ADDENDA FOR TABLE O.
(*Continued.*)

Important Stone Structures of the United States.

LOCALITY	STRUCTURE	MATERIAL
Pensacola	Court-house and P. O.	Limestone, Bowling Green, Ky.
Peoria, Ill	....do	Sandstone, Amherst, O.
Philadelphia, Pa	Custom-house	Marble, Montgomery Co., Pa.
Pittsburg, Pa	Court-house and P. O.	Granite, E. Blue Hill, Me.
....do	Allegheny Co., Court-house.	Granite, Milford Mass.
....do	Pittsburg Bank	Granite, Troy, N. H.
Portland, Me	Custom-house	Granite, Concord, N. H., and Hollowell, Me.
Portland, Ore	Custom-house and P. O.	Sandstone, near Astoria
Port Townsend, Wash	....do	Sandstone, Bellingham Bay, Washington
Providence, R. I	State-house	Marble, Pickens Co., Ga.
....do	Custom-house and P. O.	Granite, Quincy, Mass.
Quincy, Ill	Court-house and P. O.	Oolitic Limestone, Bedford, Ind.
Raleigh, N. C	....do	Granite, Goldsboro, N. C.
Rochester, N. Y	....do	Sandstone, Portland, Conn.
Rockford, Ill	Post-office	Red Sandstone, Portage, Mich.
San Francisco, Cal	....do	Granite, Rocklin, Cal.
San Jose, Cal	....do	Sandstone, San Jose, Cal.
Savannah, Ga	Court-house and P. O.	Cherokee Marble, Pickens Co., Ga.
Scranton, Pa	Post-office	Granite, Hurricane Island, Me.
Sioux City, Ia	Court-house and P. O.	Limestone. Bedford, Ind.
Sioux Falls, S. D	....do	Quartzite, East Sioux Falls, S. D.
Springfield, Ill	....do	Limestone, Nauvoo, Ill.
Springfield, Mass	Post-office	Sandstone, Longmeadow, Mass.
St. Augustine, Fla	Court-house and P. O.	Coquina, St. Augustine, Fla.
St. Louis, Mo	....do	Granite, Hurricane Island, Me.
Stanford University, Cal.	University buildings	Sandstone, Santa Clara Co., Cal.
Trenton, N. J	Custom-house and P. O.	Sandstone, Amherst, O.
Washington, D. C	Post-office	Granite, Vinalhaven, Me.
....do	New Corcoran Art Gallery	Marble, Pickens Co., Ga.
....do	New Public Library	Marble, Proctor, Vt.
Wichita, Kansas	Court-house and P. O.	Limestone, Bedford, Ind.
Wilmington, N. C	Custom-house and P. O.	Sandstone, Sanford, N. C.
Worcester, Mass	City Hall	Granite, Milford, Mass.

TABLE P.

THE EFFECT OF HEAT ON VARIOUS BUILDING STONES.*

Kind.	Locality.	Weight per cubic foot in pounds.	Ratio of absorption.	First appearance of injury. Degrees F.	First appearance of cracking or crumbling. Degrees F.	General cracking and friability. Degrees F.	Rendered worthless. Deg. F.	Melted or destroyed. Degrees F.
Light colored granite.......	Hallowell, Me..............	164.8	1-790	800	900	950	1,000	1,100
Red granite................	Stark, N. H................	164.1	1-534	600	700	800	850	950
Carter's Quarry granite....	Woodbury, Vt.......	165.8	1-784	800	900	950	1,000	1,200
Syenite	Quincy, Mass.............	166.2	1-650	750	800	850	900	1,000
Common granite...	Woodstock, Md............	165.5	1-394	700	750	800	900	900
Old Dominion Quarry granite.......	Richmond, Va.............	167.7	1-402	750	800	850	900	1,000
Light colored granite.......	St. Cloud, Minn............	168.2	1-280	700	700	800	850	900
Sandstone	Portland, Conn	148.7	1-27	850	900	950	1,000	1,100
Sandstone	Seneca, Md................	150.6	1-40	900	1,000	1,100	1,200	1,200
Sandstone	Nova Scotia...............	151.5	1-240	900	950	1,000	1,000	1,100
Potsdam sandstone........	McBride's Corners, O......	145.8	1-28	800	850	900	1.000	1,100
Berea sandstone...........	Berea, O..................	140.8	1-20	850	900	950	1,000	1,000
Limestone.................	Baltimore, Md	181.8	2-340	900	1,000	1,100	1,200	1,200
Limestone................	Bedford, Ind...............	154 8	1-280	850	900	1,000	1.200	1,200
Cincinnati limestone. ...	Hamilton County, O.......	137.7	1-28	850	900	950	1,200	1,200
Potts' blue limestone......	Springfield, Penn..........	166.6	1-280	850	850	900	1,000	1,200
Dolomite limestone........	Owen Sound, P. O.........	160.6	1-480	850	900	1,100	1,200	1,200
Trenton limestone.........	Montreal, P. Q............	169.1	1-316	900	950	1,000	1,200	1,200
Limestone.......	Isle La Motte, Vt..........	168.5	1-320	950	1,000	1,100	1,200	1,200
Tuckahoe marble..........	Westchester County, N. Y.	174 6	1-298	900	1,000	1,200	1,200	1,200
Ashley Falls marble.......	Ashley Falls, N. Y........	171.3	1-280	900	1,000	1,100	1,200	1,200
Snowflake marble..........	Westchester County, N.Y..	178.0	1-380	950	950	1,000	1,200	1,200
Tennessee marble..........	Dougherty's Quarry, East Tennessee................	169.4	1-320	950	950	1,000	1,200	1,200
Duke marble...............	Near Harper's Ferry, Va...	175.7	1-340	1,000	1,000	1,100	1,200	1,200
Black marble..........	Isle La Motte, Vt..........	176.6	1-320	1.000	1.000	1,100	1.200	1,200
Sutherland Falls marble...	Rutland, Vt................	166.6	1-342	1,000	1,000	1,100	1,200	1,200
Conglomerate....	Roxbury, Mass.....	169.2	1-49	700	800	900	1,000	1,000
Potomac stone.............	Point of Rocks, Md........	170 2	1-60	600	700	800	900	900
Conglomerate....	Caps a La Aisle, P. Q......	165.3	1-80	600	700	800	900	900
Artificial stone............	McMurtire and Chamberlain Patent	139.7	1-280	750	800	1,100	1,200	......

* From "Notes on Building Stones," by Dr. Hiram Cutting, Montpelier, Vt., 1880.

"The experience of the citizens of North Arkansas is that marble is much superior to the sandstone in withstanding heat; and because of this fact, where chimneys are built of sandstone the fireplaces are lined with marble."

See also "The Fire-Resisting Qualities of Some New Jersey Building Stones," by W. E. McCourt, in Annual Report of the State Geologist, 1907.

TABLE Q.*

Table Q shows the principal mineralogical, chemical, and physical characteristics of 38 kinds of slate described by Mr. T. Nelson Dale in Bulletin No. 275, Series A., Economic Geology, 63, "Slate Deposits and Slate Industry of the United States," for 1906, as far as these manifestly bear upon their economic value. These slates are from Arkansas, California, Maine, Maryland, New York, Pennsylvania, Vermont, Virginia and West Virginia. The columns headed "strength" and "toughness" refer to the tests by Professor Mansfield Merriman, whose methods of experimentation are described on page 47 of the Bulletin referred to. "Microscopic texture," refers primarily to the matrix or body of the slate. By "crystalline" is meant that the matrix consists of interlacing and overlapping scales and fibers of muscovite and is, therefore, a mica-slate or technically a phyllite-slate, although it may inclose unaltered particles of sedimentary origin. Such a slate should have, other things being equal, greater elasticity (toughness) and strength than one in which there is no such texture, or in which it is only incipient. The fineness or coarseness of this crystalline texture probably has a bearing upon the strength and toughness of the slate, but physical data are not sufficient to show this. The coarse-textured Peach Bottom slates, which really approach a mica schist, are the strongest of the twelve kinds of American slates tested, but they are less flexible than all the other kinds tested. In the "grade of fissility," 1 signifies a perfect slaty cleavage and 4 a very imperfect one. The column of "chief mineral constituents" includes only the four or five principal ones seen under the microscope, or whose presence has been otherwise determined, and these are given in the descending order of their probable abundance.

TABLE Q.* FIRST PART.

COMPARATIVE CHARACTERISTICS OF VARIOUS SLATES.

State	Locality, quarry, bed	Color	Cleavage surface	Luster	Magnetite	Microscopic texture
Arkansas	Mena, Polk County	Black	Remarkably fine	Slight	Some	Crystalline, extremely fine, homogenous.
....do	....do	Dark reddish	Roughish, speckled	Almost none	Very little	Crystalline, fine
....do	Mammoth Red and Lost Hannah, Polk County.	Reddish	Fine	None	....do	....do
....do	Mena, Polk County	Greenish gray	Roughish	Waxy	....do	Crystalline, extremely fine, homogeneous.
....do	Mammoth Red, Polk County	Light greenish	Very fine	Almost none	Little	....do
....do	Sec. 25, T. 3 S., R. 29 W., Polk County.	Dark-bluish gray	Fine	Slight	Very little	Crystalline, fine
....do	Sec. 30, T. 3 S., R. 28 W., Polk County.	Light gray	Roughish	None	....do	....do
....do	Southwest Slate Mfg. Co., Polk County.	Very dark gray	Roughish, spangled	Almost none	....do	Crystalline, coarse, granular.
California	Eureka quarry, Eldorado County.	....do	Fine	Bright	....do	Crystalline, fine
Maine	Merrill quarry, Brownville	....do	Very fine	Very bright	Much	Crystalline, very fine
....do	North Blanchard	....do	Roughish	Slight	None	Crystalline, fine
....do	Monson Pond, Monson	....do	....do	Almost none	Very little	Crystalline, fine, but particles irregular.
....do	Maine Slate Co., of Monson	....do	....do	Bright	....do	Crystalline, very fine
....do	West Monson	....do	Very fine	Somewhat bright	None	Crystalline, fine
Maryland	Thurston	Dark purplish	Slightly granular	....do	....do	Crystalline, fine, particles irregular.
New York	Granville and Hampton	Reddish	Fine or roughish, speckled.	None	Some	....do
....do	....do	Bright greenish	....do	....do	....do	....do
Pennsylvania	Old Bangor, Northampton County.	Very dark gray	Fine	Almost none	Very little	Crystalline, fine
....do	North Bangor, Northampton County.	....do	....do	....do	Some	....do

* Taken from "Slate Deposits and Slate Industry of the United States," Bulletin No. 275, Series A., Economic Geology, 63, Department of the Interior, United States Geogical Survey, Washington, D. C., 1906.

TABLE Q. FIRST PART (Continued).

COMPARATIVE CHARACTERISTICS OF VARIOUS SLATES (Continued).

State	Locality, quarry, bed	Color	Cleavage surface	Lustre	Magnetite	Microscopic texture
Pennsylvania	Albion, Pen Argyl	Very dark gray	Roughish	Almost none	Some	Crystalline, fine
do.	Albion, Gray bed	Very dark greenish.	Roughish, granular	do.	Little	do.
do.	Heimbach, Big bed, Northampton County.	Very dark gray, not bluish.	Somewhat fine	do.	Extremely little.	do.
do.	Heimbach, Black bed	Bluish black	Roughish	None	Very little	do.
do.	East Bangor Consolidated, Northampton County.	Very dark bluish gray.	Somewhat fine	Almost none	Some	do.
do.	Slatington, Lehigh County	do.	do.	do.	Little	do.
do.	Chapman "hard vein"	Very dark gray	Slightly roughish	Slight	Some	do.
Pennsylvania-Maryland.	Peach Bottom	Very dark bluish gray.	Minutely granular	Very bright	do.	Crystalline, coarse
Vermont	Northfield, Vermont Black Slate Co.	Very dark gray	Very fine	do.	Very little	Crystalline, very fine
do.	"Sea green"	Gray greenish	Fine	Waxy	do.	do.
do.	Purplish of "sea green"	Purplish brown	do.	None	do.	do.
do.	"Unfading green"	Greenish gray	Roughish	do.	Some	Crystalline, irregluar
do.	Purplish of "unfading"	Purplish brown	do.	do.	do.	do.
do.	Benson (prospect)	Bluish black	Somewhat fine	Slight	Very little	Crystalline, fine
Virginia	Arvonia, Williams	Very dark greenish gray.	Minutely granular	Very bright	do.	Crystalline, irregular
do.	Arvonia, Fontaine	do.	Granular	do.	do.	Crystalline, irregular, coarse.
do.	Bremo (prospect)	Dark gray	Fine speckled	do.	None	Crystalline, fine
do.	Snowden	Very dark gray	Minutely granular	Almost none	do.	Crystalline, fine, irregular.
West Virginia	Martinsburg	Black, brownish hue.	Roughish	None	Little	Not crystalline or imperfectly so, coarse.

TABLE Q. SECOND PART.

COMPARATIVE CHARACTERISTICS OF VARIOUS SLATES. (Continued).

State	Grade of fissility	Chief minerals *a*	Carbonate	Lime by analysis	Strength, pounds per square inch *b*	Toughness *c*	Remarks
Arkansas	1	Muscov., carbon, quartz, pyrite	None				Strength, toughness, and behavior in freezing and thawing should be tested.
do	3	Muscov., hematite, kaolin, quartz	do				
do	1	Muscov., hematite, kaolin, quartz, chlorite.	do				Do.
do	3	Muscov., quartz, kaolin, chlorite	do				Specimen shows two extra foliations, which will prove directions of weakness.
do	1	Muscov., quartz, kaolin, chlorite	do				Strength, toughness, and behavior in freezing and thawing should be tested.
do	2	Muscov., quartz, pyrite, carbon	do				
do	2	Muscov., quartz, chlorite, kaolin	do				Some limonite staining from pyrite.
do	3	Muscov., quartz, carbon, pyrite	Some				Between a metamorphic grit and a slate.
California	2	Muscov., quartz, chorite, carbon	do	0.98			See test, p. 47 of Bulletin.
Maine	1	Muscov., quartz, magnetite, pyrite.	None		9,880	0.200	See p. 66 on amount of magnetite. See tests on p. 66 of Bulletin.
do	3	Muscov., chlorite, quartz, pyrite	do				Very sonorous.
do	3	Muscov., quartz, chlorite, biotite	do	0.52			Very sonorous. See tests on p. 63 of Bulletin.
do	2	Muscov., quartz, biotite, chlorite	do				Very sonorous.
do	2	Muscov., quartz, chlorite, pyrite	do		9,130	0 205	Very sonorous. See tests on p. 123 of Bulletin.
Maryland	3	Muscov., chlorite, quartz, talc	do				Sonorousness very moderate; can be sawn with handsaw.
New York	3	Muscov., quartz, hematite, kaolin, carb.	Much	0.11 5.11	9,220	0.232	Becomes brighter on exposure. Little or no ferrous carbonate. Impact test shows 126.66 foot-pounds of work per pound of slate. See tests on pp. 49, 124 of Bulletin.
do	3	Muscov., quartz, chlorite, carbon, magnetite.	Less than red, usually.	1.43	8,050	0.190	Said to be unfading. See tests on p. 123, B'l't'n.
Pennsylvania	1	Muscov., carb., quartz, kaolin	Quite a little	4.38	9,810	0.312	Discolors on continued exposure. Impact tests of various Northampton and Lehigh County slates show from 3.50 to 5.44 foot-pounds of work per pound of slate. See tests on p. 124.
do	1	Muscov., carb., quartz, kaolin	Much				Do.
do	1	Muscov., carb., quartz, chlorite	Quite a little	4.09	7,150	0.270	Do. (See p. 79 of Bulletin.)
do	1	Muscov., carb., quartz, chlorite	do				
do	1	Muscov., carb., quartz, pyrite	Very much				Do.

a Carb. = carbonate; carbon. = carbonaceous matter or graphite.
b Tests by Merriman.
c Deflection, in inches, on supports 22 inches apart: tests by Merriman.

TABLE Q. SECOND PART (Continued).
COMPARATIVE CHARACTERISTICS OF VARIOUS SLATES. (Continued).

State	Grade of fissility	Chief minerals *a*	Carbonate	Lime by analy-	Strength, pounds per square inch *b*	Toughness *c*	Remarks
Pennsylvania.	1	Muscov., carb., quartz, carbon.	....do......	....	....	......	Discolors on continued exposure.
....do.......	1	Muscov., carb., quartz, pyrite, chlorite.	Much.......	....	....	......	In ribboned slate from this quarry the percentage of quartz would be higher than in the rest. Impact tests of various Northampton and Lehigh County slates show from 3.50 to 5.44 foot-pounds of work per pound of slate. See tests on p. 124 of Bulletin.
....do.......	1	Muscov., carb., quartz, kaolin....	....do.......	4.23	....	......	Discolors on continued exposure. Impact tests of various Northampton and Lehigh County slates show from 3.50 to 5.44 foot-pounds of work per pound of slate. See tests on pp. 47, 124 of Bulletin.
....do.......	2	Muscov., quartz, carb., pyrite....	Quite a little.	2.83–3.40	9,460	0.212	Discolors less readily than any of the above Pennsylvania slates. Impact tests of various Northampton and Lehigh County slates show from 3.50 to 5.44 foot-pounds of work per pound of slate. See tests on p. 124. B'n.
Pennsylvania-Maryland.	2	Muscov., quartz, graphite, andalusite, magnetite.	None......	0.155–0.48	11,260	0.93	Very sonorous. Impact tests show from 8.49 to 24.17 foot-pounds of work per pound of slate. See tests on p. 124 of Bulletin
Vermont......	1	Muscov., quartz, pyrite, magnetite.	Very little...	....	....	......	Very sonorous.
....do.......	1	Muscov., quartz, carb., chlorite...	Much........	0.63–2.20	7,250	0.207	Becomes brownish gray on continued exposure. See tests on p. 123 of Bulletin.
....do.......	1	Muscov., quartz, carb., hematite..	Some........	0.50–0.71	....	......	Discoloration less pronounced than that of "sea green."
....do.......	2	Muscov., quartz, chlorite, carb....	Very little...	0.42–0.56	6,410	0.225	Preserves nearly all its color on continued exposure. See tests on p. 124 of Bulletin.
....do.......	2	Muscov., quartz, chlorite, hematite.	....do......	....	....	......	Do.
....do.......	2	Muscov., quartz, carb., pyrite..	Much.......	1.27	....	......	Sonorous. Probably "fading."
Virginia......	2	Muscov., quartz, biotite, carb carbon.	Some.......	....	9,040	0.227	Very sonorous. See tests on p. 123 of Bulletin.
....do.......	2	Muscov., quartz, biotite, carb., pyrite.	....do......	....	9,850	0.225	Do.
....do.......	1	Muscov., quartz, pyrite, kaolin?..	None.......	....	....	......	
....do.......	2	Muscov., quartz, chlorite, kaolin.	Little.......	....	....	......	Very sonorous.
West Virginia.	3	Carb., muscov., quartz, kaolin, pyrite, carbon.	From some to much.	1.11 and over.	....	......	Analysis by W. C. Tilden. In some specimens muscovite equals the carbonate in amount.

a Carb. = carbonate; carbon. = carbonaceous matter or graphite.
b Tests by Merriman.
c Deflection, in inches, on supports 22 inches apart; tests by Merriman.

ADDITION DATA TO ACCOMPANY TABLES Q.

To the comparative data of the preceding Tables Q should be added the results of a few tests not easily tabulated.

Professor Mansfield Merriman's later corrosion tests show the following percentages of loss in weight after immersion in acid solution for 360 hours: Pennsylvania slates, 1.68 to 2.76; Peach Bottom, 1.11 to 1.29; red of New York and Vermont, 0.25. During this test the Pennsylvania slates become a grayish white, some of the Peach Bottom slates change but slightly, others are almost unaffected; the red slates likewise remain almost unaffected.[a]

Mr. E. H. S. Bailey's tests of porosity give these indices of porosity: "Hard Vein" Pennsylvania Chapman, 0.11—0.14; Daniel quarry, 0.14; Belfast quarry, 0.25; red of New York and Vermont, 0.21.[b]

Mr. J. F. William's tests of the compression of columns of slate 10 inches in length by 1 inch in cross-section with the cleavage vertical, show that the purplish of the unfading green series of Vermont stands 20,000 pounds, the unfading green, 16,020 pounds and the red of New York and Vermont, 17,730 pounds.[c]

The following results of various tests of Maine (Monson) slate made at the United States Arsenal at Watertown, Mass., were republished from the War Department reports in the Twentieth Annual Report of the United States Geological Survey, Part VI (continued), 1899, p. 395:

	POUNDS.
Maximum fiber stress per square inch	7,671
Shearing test per square inch	2,192
Ultimate compressive strength per square inch	19,510

Coefficient of expansion, 0.000005.

The relative commercial value of several slates is an index of their physical characteristics. Mathews, in 1898, gave these prices for slates 14 by 7 inches, three-sixteenths thick, per square; Peach Bottom, \$4.85; Northampton County, Pa., \$3.50; Lehigh County, Pa., \$3.40—\$3.95; Maine (No. 1), \$6.40; Arvonia, Va., \$3.60; unfading green, Vermont, \$4.50; red, New York, \$11.

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a Trans. Am. Soc. Civ. Eng., vol. 32, p. 538.
b Loc. cit., p. 542.
c Loc. cit., p. 132 (see Bibliography, p. 145 of Mr. Dale's Bulletin, No. 275).

The following prices per square for slates, No. 1 quality, 16 by 8 inches, f. o. b., were obtained by Doctor Day from producers for January, 1905: Peach Bottom, \$6.35; Monson, Me., \$7.20; red, New York, \$11; Bangor, Pa., \$5.75; Albion, Pa., \$5; Pen Argyl, Pa., \$4.75; Chapman, Pa., hard vein, \$5.25; Slatington, Pa., \$4.50 to \$5; unfading green, Vermont, \$4.50 to \$5.25; sea green, Vermont, \$3.50; Virginia, \$5 to \$5.50.

Slates may be classified as follows:

CLASSIFICATION OF SLATE.

(I) *Aqueous sedimentary.*

- (A) *Clay slates:* Matrix without any or with but very faint aggregate polarization.
- (B) *Mica slates:* Matrix with marked aggregate polarization.
  - (1) Fading: With sufficient $FeCO_3$ to discolor considerably on prolonged exposure.
    - (*a*) Carbonaceous or graphitic.
    - (*b*) Chloritic (greenish).
    - (*c*) Hematitic and chloritic (purplish).
  - (2) Unfading: Without sufficient $FeCO_3$ to produce any but very slight discoloration on prolonged exposure.
    - (*a*) Graphitic.
    - (*b*) Hematitic (reddish).
    - (*c*) Chloritic (greenish).
    - (*d*) Hematitic and chloritic (purplish).

(II) *Igneous.*

- (A) *Ash slates.*
- (B) *Dike slates.*

In accordance with this scheme of classification of slates, most of the slates whose characteristics are given in the preceding Table Q are here arranged systematically:

(A) *Clay-slates* (Fading) Martinsburg, W. Va.

(B) *Mica-slates*

- (Fading)
  - (a) Carbonaceous or graphitic (Blackish). — Lehigh and Northhampton counties, Pa. Benson, Vt.
  - (b) Chloritic (greenish). "Sea green," Vermont.
  - (c) Hematitic and Chloritic (purplish). Purplish of Pawlet and Poultney, Vt.
- (Unfading)
  - (a) Graphitic or carbonaceous (blackish). — Peach Bottom, Pa. and Md. Arvonia, Va. Northfield, Vt. Brownville, Monson, Me. North Blanchard, Me. West Monson, Me.
  - (b) Hematitic (reddish). — Granville, Hampton, N. Y.; Polk Co., Ark.
  - (c) Chloritic (greenish). "Unfading green," Vermont.
  - (d) Hematitic and chloritic (purplish). — Purplish of Fair Haven, Vt. Thurston, Md.

TABLE R.*

The following table shows the number of permits and the cost of buildings erected thereunder in the leading cities of the country in 1905 and 1906, the increase or decrease in the cost of the buildings erected in each city in 1906, and the total increase, together with the percentage of increase or decrease in each case, and the percentage of the total increase; also the number and value of the fire-proof buildings, with their cost, and the number of wooden buildings, with their cost. In some instances more than one building is erected under the same permit; the cost given is that of the building or buildings erected.

TABLE R.*

BUILDING OPERATIONS IN THE LEADING CITIES OF THE UNITED STATES IN 1905 AND 1906.

City	1905 Number of permits or buildings	1905 Cost of buildings	1906 Number of permits or buildings	1906 Cost of buildings	Gain (+) or loss (—) in 1906	Percentage of gain or loss in 1906
Allegheny, Pa......	816	$2,412,570	713	$2,080,634	— $331,936	— 15.95
Atlanta, Ga........	3,499	3,312,931	3,741	5,156,149	+ 1,843,218	+ 55.63
Baltimore, Md.....	2,976	16,638,200	2,826	12,619,970	— 4,018,230	— 24.15
Boston, Mass......	2,249	12,364,747	3,328	23,064,741	+10,699,994	+ 86.53
Brooklyn, N. Y.....	19,679	73,017,706	18,083	71,442,148	— 1,575,558	— 2.15
Buffalo, N. Y......	2,886	7,401,006	2,867	8,686,030	+ 1,285,024	+ 17.36
Cambridge, Mass...	470	1,659,875	457	1,458,105	— 201,770	— 12.15
Chicago, Ill........	16,150	65,000,000	10,641	64,709,325	— 290,675	— .44
Cincinnati, Ohio....	3,307	9,709,450	2,130	7,065,746	— 2,643,704	— 27.22
Cleveland, Ohio....	4,976	9,777,145	7,553	12,972,974	+ 3,195,829	+ 32.68
Columbus, Ohio....	2,133	5,107,400	2,025	4,006,175	— 1,101,225	— 21.56
Dayton, Ohio......	1,176	2,350,000	1,223	2,898,380	+ 548,380	+ 23.33
Denver, Colo.......	2.455	6,374,537	2,461	7,000,996	+ 626,459	+ 9.82
Detroit, Mich......	4,021	10,462,100	4,105	13,275,250	+ 2,813,150	+ 26.88
Fall River, Mass...	291	885,625	275	939,325	+ 53,700	+ 6.06
Grand Rapids, Mich.	1,486	2,145,265	1,250	2,181,307	+ 36,042	+ 1.68
Hartford, Conn....	664	3,076,092	652	3,732,915	+ 656,823	+ 21.35
Indianapolis, Ind...	4,041	7,225,325	3,825	5,530,998	— 1,694,327	— 23.44
Jersey City, N. J...	1,352	3,330,522	1,503	4,334,244	+ 1,003,722	+ 30.13
Kansas City, Kans.	818	1,172,093	541	3,622,670	+ 2,450,577	+209.07
Kansas City, Mo...	4,437	10,917,024	3,993	10,765,480	— 151,544	— 1.38
Los Angeles, Cal...	9,543	15,382,057	9,358	18,502,446	+ 3,120,389	+ 20.28
Louisville, Ky.....	2,255	4,506,382	2,916	5,116,917	+ 610,535	+ 13.54
Lowell, Mass.......	251	878,090	353	901,745	+ 23,655	+ 2.69
Memphis, Tenn....	2,882	3,554,883	2,549	4,346,767	+ 791,884	+ 22.27
Milwaukee, Wis....	4,166	9,806,729	3,782	9,713,284	— 93,445	— .95
Minneapolis, Minn..	4,825	8,905,205	4,724	9,466,150	+ 560,945	+ 6.29
Nashville, Tenn....	5,636	2,609,889	5,124	2,840,212	+ 230,323	+ 8.82
Newark, N. J......	2,379	10,214,615	1,946	10,411,328	+ 196,713	+ 1.92
New Haven, Conn..	467	2,143,240	687	3,018,890	+ 875,650	+ 40.85
New Orleans, La...	1,970	4,070,077	....	5,098,773	+ 1,028,696	+ 25.27
New York, N. Y....	10,043	178,032,527	8,573	154,964,655	—23,067,872	— 12.95
Omaha, Nebr......	885	4,387,464	1,093	4,273,050	— 114,414	— 2.60
Philadelphia, Pa....	15,933	34,416,745	17,872	40,711,510	+ 6,294,765	+ 18.28
Pittsburg, Pa.......	4,273	17,159,443	3,738	15,370,047	— 1,789,396	— 10.42
Providence, R. I....	1,358	4,562,950	1,350	3,983,300	— 579,650	— 12.70
Reading, Pa.......	1,548	2,791,065	1,347	1,645,135	— 1,145,930	— 41.05
Richmond, Va.....	451	1,501,000	740	2,504,895	+ 1,003,895	+ 66.88
Rochester, N. Y....	1,707	5,676,624	1,373	6,175,478	+ 498,854	+ 8.78
St. Joseph, Mo.....	877	670,195	898	1,052,746	+ 382,551	+ 57.08
St. Louis, Mo......	8,285	23,434,734	8,988	29,938,693	+ 6,503,959	+ 27.74
St. Paul, Minn.....	1,657	8,536,345	2,813	9,537,449	+ 1,001,104	+ 11.72
San Francisco, Cal.	5,420	18,268,753	5,686	34,927,396	+16,658,643	+ 91.18
Scranton, Pa.......	1,144	2,212,929	1,097	2,174,075	— 38,854	— 1.75
Seattle, Wash......	7,677	6,704,784	7,194	11,875,397	+ 5,170,613	+ 77.11
Syracuse, N. Y.....	837	2,275,610	1,057	3,313,261	+ 1,037,651	+ 45.59
Toledo, Ohio.......	1,139	3,087,142	1,759	4,696,058	+ 1,608,916	+ 52.12
Washington, D. C...	7,577	12,308,943	8,453	11,668,347	— 640,596	— 5.20
Worcester, Mass....	739	2,182,840	912	2,939,403	+ 756,563	+ 34.65
Total.........	185,806	644,620,873	180,574	678,710,969	+34,090,096	+ 5.29

* Taken from "Mineral Resources of the United States," for 1906.

TABLE S.*

In 1906 the attempt was made for the first time to obtain the statistics of the brick and stone or fire-proof buildings as compared with those of wood. Of the 49 cities reporting, 35 were able to give figures showing these classes of buildings, and the results are given in the following table:

TABLE S.*

CHARACTER OF BUILDINGS ERECTED IN THE LEADING CITIES OF THE UNITED STATES IN 1906.

	Brick and stone		Wood	
	Number of permits	Value	Number of permits	Value
Atlanta, Ga.	134	$2,189,327	1,336	$2,167,921
Boston, Mass.	479	14,255 431	1,156	5,855,231
Brooklyn, N. Y.	5,802	55,586,860	2,782	9,479,465
Chicago, Ill.	5,967	58,238,393	4,674	6,470,932
Cincinnati, Ohio	503	4,691,400	748	1,617,290
Cleveland, Ohio	694	6,694,580	3,582	4,953,193
Columbus, Ohio	594	2,193,075	1,125	1,687,300
Dayton, Ohio	126	1,319,080	910	1,411,870
Grand Rapids, Mich.	73	698,681	763	1,175,424
Hartford, Conn.	127	2,748,900	136	637,800
Indianapolis, Ind.	721	1,954,594	1,903	3,030,592
Kansas City, Mo.	413	5,544,000	1,621	3,783,710
Los Angeles, Cal.	273	6,489,367	6,564	10,536,473
Louisville, Ky.	201	2,877,015	1,415	1,566,530
Lowell, Mass.	12	304,109	164	421,155
Memphis, Tenn.	154	2,193,458	1,373	1,782,214
Milwaukee, Wis.	179	3,532,328	1,633	4,433,820
Nashville, Tenn.	259	2,056,750	458	484,579
Newark, N. J.	155	5,067,445	1,791	4,740,929
New Haven, Conn.	87	1,571,600	257	1,183,100
New York, N. Y.	2,588	129,927,135	1,279	5,673,110
Omaha, Nebr.	157	2,614,400	712	1,493,560
Philadelphia, Pa.	10,987	33,034,770	67	123,450
Providence, R. I.	53	1,187,400	719	1,979,400
Reading, Pa.	884	1,631,245	....	....
Richmond, Va.	293	1,549,576	337	333,207
Rochester, N. Y.	159	2,414,739	779	3,031,702
St. Louis, Mo.	2,640	27,223,734	3,956	993,332
San Francisco, Cal.	599	16,374,092	3,258	14,458,894
Scranton, Pa.	60	538,015	518	1,197,800
Seattle, Wash.	81	5,001,150	3,170	4,751,329
Syracuse, N. Y.	81	1,564,959	511	1,360,737
Toledo, Ohio	110	1,629,997	1,542	2,525,960
Washington, D. C.	1,349	9,405,200	1,181	1,089,177
Worcester, Mass.	72	1,135,295	394	1,067,105
Total	37,066	415,438,100	52,814	107,498,291

Of the total number of permits or buildings, 37,066, or 41.24 per cent, were brick or stone buildings, and 52,814, or 58.76 per cent,

* Taken from "Mineral Resources of the United States," for 1906.

were wooden buildings. The total value of the new buildings in these cities was $522,936,391. Of this, $415,438,100, or 79.44 per cent, represented buildings of stone, brick, or other so-called fire-proof material, and $107,498,291, or 20.56 per cent, represented wooden buildings. The number of wooden buildings even in these large cities is considerably greater (42.49 per cent) than the number of fire-proof buildings, but the value of the wooden buildings was only a little more than one-fourth of that of the fire-proof buildings. The average value of each of the fire-proof buildings was $11,208, while the wooden buildings averaged only $2,035.

New York leads in the value of its fire-proof buildings, though the number erected was not very large. The average value per building was $50,204. There were no wooden buildings erected in the borough of Manhattan, but in the Bronx 1,279 were erected in 1906, with an average value of $4,436. Chicago was second in value of fire-proof buildings, though the average value per building was but $9,760, and Brooklyn was third, with an average value of $9,581. Philadelphia reported the largest number of brick buildings, 10,987, of an average value of $3,007. In St. Louis the average value of fire-proof buildings was $10,312.

TABLE T.*

In the following table will be found a comparison of the several varieties of clay products marketed in 1905 and 1906, showing the actual gain or loss in each variety and the percentage of gain or loss in each variety:

This table, more than any other, exhibits the industry in 1906 as compared with 1905 and is interesting as giving the status of the various branches. It will be observed that only three products showed a decrease from 1905, and in the only important one, common brick, the loss was so small as to be negligible. All other important branches showed large gains in 1906.

The product showing the largest actual gain was fire-brick, which increased $1,471,464, or 11.55 per cent. Next to common brick this is the product of largest value, reporting $14,206,868, as against $12,735,404 in 1905.

The next largest actual gain was in vitrified paving, $1,154,058,

TABLE T.*

VALUE OF THE PRODUCTS OF CLAY IN THE UNITED STATES IN 1905 AND 1906, WITH INCREASE OR DECREASE.

Product	1905	1906	Increase in 1906	Percentage of increase in 1906
Common brick	$61,394,383	$61,300,696	*a*$93,687	*a*0.15
Vitrified paving brick or block	6,703,710	7,857,768	1,154,058	17.22
Front brick	7,108,092	7,895,323	787,231	11.08
Fancy or ornamental brick	293,907	207,119	*a*86,788	*a*29.53
Enameled brick	636,279	773,104	136,825	21.50
Drain tile	5,850,210	6,543,289	693,079	11.85
Sewer pipe	10,097,089	11,114,967	1,017,878	10.08
Architectural terra-cotta	5,003,158	5,739,460	736,302	14.72
Fire-proofing and terra-cotta lumber	3,004,526	3,652,181	647,655	21.56
Hollow building tile or blocks	1,094,267	934,357	*a*159,910	*a*14.61
Tile (not drain)	3,647,726	4,634,898	987,172	27.06
Stove lining	645,432	743,414	97,982	15.18
Fire-brick	12,735,404	14,206,868	1,471,464	11.55
Miscellaneous	3,564,111	3,988,394	424,283	11.90
Total brick and tile	121,778,294	129,591,838	7,813,544	6.42
Total pottery	27,918,894	31,440,884	3,521,990	12.62
Grand total	149,697,188	161,032,722	11,335,534	7.57

a Decrease.

or 17.22 per cent. The year 1905 was unquestionably below the normal in this industry, owing to local conditions, and in 1906 the industry was where it should normally have been. The undoubted merit of vitrified brick when properly laid as a paving material is becoming realized more and more, partly as a result of the educational campaign carried on by the makers of this product, and its future increased use seems assured. The use of this variety of brick in buildings also is increasing, as its advantages for this character of work become known.

The product showing the largest proportional gain was tile (not drain) including wall, floor, and roofing tile; this product showed a gain of 27.06 per cent and is likely to continue to show large proportional gains, though the actual gain was but $987,172. This product is the fourth in actual gain, being exceeded only by fire-brick, vitrified brick, and sewer pipe.

* Taken from "Mineral Resources of the United States," for 1906.

TABLE U.*

The following table shows the products of clay in the United States from 1897 to 1906 inclusive, by varieties of product, together with the total for each year and the number of operating firms reported.

This table shows the wonderful growth of this industry and its great importance. In these ten years the value of clay products has increased nearly 100,000,000, or 158.23 per cent, the exact figures being from $62,359,991 in 1897 to $161,032,722 in 1906.

Only three products failed to reach their maximum value in 1906, namely: common brick, fancy or ornamental brick, and hollow building tile or block, and in the value of these products the decrease from the maximum was very slight. In fact, although the value of the common brick did not equal the maximum of 1905, the quantity reached a maximum of 10,027,039,000. Fancy or ornamental brick and hollow building brick or tile have for some years been decreasing almost steadily. Common brick increased from the minimum, 5,292,532,000 in 1897, to 10,027,039,000 in 1906, an increase of 4,734,507,000, or 89.45 per cent, in ten years; the value ranged from $26,430,207 in 1897 to the maximum, $61,394,383 in 1905, a gain of $34,964,176 or 132 per cent. The price per thousand varied from $4.99 in 1897 to $6.25 in 1905.

TABLE U.*

PRODUCTS OF CLAY IN THE UNITED STATES, 1897—1906, BY VARIETIES.

Year	No. of operating firms reporting	Common brick			Vitrified paving brick		
		Quantity (thousands)	Value	Average price per thousand	Quantity (thousands)	Value	Average price per thousand
1897....	5,424	5,292,532	$26,430,207	$4.99	435,851	$3,582,037	$8 22
1898....	5,971	5,867,415	30,980,704	5.28	474,419	4,016,822	8.47
1899....	6,962	7,695,305	39,887,522	5.18	580,751	4,750,424	8.18
1900....	6,475	7,140,622	38,621,514	5.41	546,679	4,764,124	8.71
1901....	6,421	8,038,579	45,503,076	5.66	605,077	5,484,134	9.06
1902....	6,046	8,475,067	48,885,869	5.77	617,192	5,744,530	9.31
1903....	6,034	8,463,683	50,532,075	5.97	654,499	6,453,849	9.86
1904....	6,108	8,665,171	51,768,558	5.97	735,489	7,557,425	10.28
1905....	5,925	9,817,355	61,394,383	6.25	665,879	6,703,710	10.07
1906....	5,857	10,027,039	61,300,696	6.11	751,974	7,857,768	10.45

Year	Front brick			Fancy or ornamental brick (value)	Enameled brick (value)	Fire-brick (value)	Stove lining (value)	Drain tile (value)
	Quantity (thousands)	Value	Average price per thousand					
1897....	310,918	$3,855,033	$12.40	$685,048	(a)	$4,094,704	(b)	$2,623,305
1898....	295,833	3,572,385	12.08	358,372	$279,993	6,093,071	(b)	3,115,318
1899....	438,817	4,767,343	10.86	476,191	329,969	8,641,882	$416,235	3,682,394
1900....	344,516	3,864,670	11.09	289,698	323,630	9,830,517	462,541	2,976,281
1901....	415,343	4,709,737	11.34	372,131	463,709	9,870,421	423,371	3,143,001
1902....	458,391	5,318,008	11.60	335,290	471,163	11,970,511	630,924	3,506,787
1903....	433,016	5,402,861	12.48	328,387	569,689	b14,062,369	(b)	4,639,214
1904....	434,351	5,560,131	12.80	300,233	545,397	11,167,972	(b)	5,348,555
1905....	541,590	7,108,092	13.12	293,907	636,279	12,735,404	645,432	5,850,210
1906....	617,469	7,895,323	12.79	207,119	773,104	14,206,868	743,414	6,543,289

Year	Sewer pipe (value)	Architectural terra-cotta (value)	Fire-proofing (value)	Hollow building tile or blocks (value)	Tile, not drain (value)	Pottery (value)	Miscellaneous (value)	Total value
1897.	$4,069,534	$1,841,422	$1,979,259	(c)	$1,476,638	$10,309,209	$1,413,595	$62,359,991
1898.	3,791,057	2,043,325	1,900,642	(c)	1,746,024	14,589,224	2,000,743	74,487,680
1899.	4,560,334	2,027,532	1,665,066	(c)	1,276,300	17,250,250	6,065,928	95,797,370
1900.	5,842,562	2,372,568	1,820,214	(c)	2,349,420	19,798,570	2,896,036	96,212,345
1901.	6,736,969	3,367,982	1,860,269	(c)	2,867,659	22,463,860	2,945,268	110,211,587
1902.	7,174,892	3,526,906	3,175,593	(c)	3,622,863	24,127,453	3,678,742	122,169,531
1903.	8,525,369	4,672,028	2,708,143	$1,153,200	3,505,329	25,436,052	3,073,856	131,062,421
1904.	9,187,423	4,107,473	2,502,603	1,126,498	3,023,428	25,158,270	3,669,282	131,023,248
1905.	10,097,089	5,003,158	3,004,526	1,094,267	3,647,726	27,918,894	3,564,111	149,697,188
1906.	11,114,967	5,739,460	3,652,181	934,357	4,634,898	31,440,884	3,988,394	161,032,722

a Enameled brick not separately classified prior to 1898.
b Stove lining not separately classified prior to 1899 is included in fire-brick in 1903; in miscellaneous in 1904.
c Hollow building tile or blocks included in fire-proofing prior to 1903.

* Taken from "Mineral Resources of the United States," for 1906.

TABLE V.*

TABULATED RESULTS OF THE ACTUAL CRUSHING STRENGTH OF BRICK PIERS. TABULATED FROM TESTS MADE BY THE U. S. GOVERNMENT AT WATERTOWN, MASS.

BUILT OF FACE-BRICKS (M. W. SANDS, CAMBRIDGE, MASS.). AGE OF PIERS, 18 TO 24 MONTHS.

Nominal Dimensions. Height.		Cross-section.		Composition of mortar.	Weight per cubic foot.	Sectional area.	First crack.	Ultimate strength. Total.	Per sq. in.	Per sq. ft.	% of single brick.
Ft.	In.	In.	In.		lbs.		lbs.	lbs.	lbs.	Tons.	
1	4	8	8	1 lime, 3 sand,	137.4	57.00	85,000	143,600	2,520	181.4	18.1
6	8	8	8	" "	133.5	57.76	50,000	108,400	1,877	135.1	13.5
1	4	8	8	1 Portland cement, 2 sand,	136.3	57.76	200,000	218,100	3,776	271.8	27.1
6	8	8	8	" "	133.5	57.76	85,000	129,900	2,249	161.9	16.2
2	0	12	12	1 lime, 3 sand,		132.25	140,000	257,100	1,940	139.7	13.9
a 2	0	12	12	" "		113.76	90,000	226,100	1,990	143.3	14.3
10	0	12	12	" "	131.7	132.25	70,000	199,800	1,511	108.8	10.9
b 10	0	12	12	" "	125.0	115.44	100,000	208,600	1,807	130.1	13.0
2	0	12	12	1 Portland cement, 2 sand,		132.25	200,000	486,000	3,670	264.2	26.4
10	0	12	12	" "	132.2	132.25	200,000	298,000	2,253	162.2	16.2
				BUILT OF COMMON BRICKS (M. W. SANDS).							
1	4	8	8	1 lime, 3 sand,	135.6	60.80	66,000	148,800	2,440	175.6	13.3
6	8	8	8	" "	133.6	62.40		96,100	1,540	110.8	8.4
2	0	12	12	" "		138.06	75,000	296,400	2,150	154.8	11.7
9	9	12	12	" "	131.5	138.06	70,000	154,300	1,118	80.5	6.1
c 10	0	12	12	" "	136.0	115.50	70,000	183,300	1,587	114.3	8.6
10	0	12	12	1 Portland cement, 2 sand,	131.0	138.06		276,600	2,003	144.2	10.9
2	8	16	16	" " "		256.00	460,000	696,000	2,720	195.8	14.8
10	0	16	16	" " "		256.00	340,000	483,100	1,887	135.8	10.8
				BUILT OF COMMON BRICKS (BAY STATE).							
d 6	0	12	12	1 lime, 3 sand,	118.2	144.00	80,000	191,600	1,331	95.8	11.7
e 6	0	12	12	" "	118.1	156.25	110,000	189,200	1,211	87.2	10.6
6	0	12	12	1 Rosendale cement, 2 lime mortar,	120.6	144.00	160,000	237,000	1,646	118.5	14.4
6	0	12	12	" " 2 sand,	123.0	144.00	260,000	284,000	1,972	142.0	17.3
6	0	12	12	1 Portland cement, 2 lime mortar,	120.3	144.00	150,000	203,200	1,411	101.6	12.4
6	0	12	12	" " 2 sand,	119.7	144.00	220,000	258,000	1,792	129.0	15.7
6	0	12	12	Neat Portland cement,	126.6	144.00	280,000	342,000	2,375	171.0	20.8

a Has hollow core 4.25x4.25 inches. *b* Has hollow core 4.1x4.1 inches. *c* Has hollow core 4.75x4.75 inches.

d Joints broken every 6 courses. *e* Bricks laid on edge.

* See also "Architect's and Builder's Pocket-Book," by Frank E. Kidder; Chapter V., "Strength of Brick and Stone Masonry and Concrete." Articles on "Working Strength of Masonry," "Brick Piers" and "Tests of the Strength of Brick Piers Laid with Various Mortars."

TABLE W.

Safe Working Loads for Masonry.

From the "Architect's and Builder's Pocket-Book," by Frank E. Kidder.

BRICKWORK IN WALLS OR PIERS.

Tons per square foot.	Eastern	Western
Red brick in lime mortar	7	5
" hydraulic lime mortar		6
" natural cement mortar, 1 to 3	10	8
Arch or pressed brick in lime mortar	8	6
" " " natural cement	12	9
" " " Portland cement	15	12½

Piers exceeding in height six times their least dimensions should be increased 4 inches in size for each addititional 6 feet.

STONEWORK.

(Tons per square foot.)	
Rubble walls, irregular stones	3
" coursed soft stone	2½
" " hard stone	5 to 16
Dimension stone, squared in cement:	
Sandstone and limestone	10 to 20
Granite	20 to 40
Dressed stone, with ⅜-inch dressed joints in cement:	
Granite	60
Marble or limestone, best	40
Sandstone	30

Height of columns not to exceed eight times least diameter.

CONCRETE.

Portland cement, 1 to 8, 6 months, 10 tons; 1 year, 15 to 20 tons	
Rosendale cement, 1 to 6, 6 months, 3 tons; 1 year, 5 to 8 tons	
Hydraulic lime, best, 1 to 6	5

HOLLOW TILES.

(Safe loads per square inch of effective bearing parts.)	
Hard fire-clay tiles	80 lbs.*
" ordinary clay tiles	60 "
Porous terra-cotta tiles	40 "

MORTARS.

(In ½-inch joints, 3 months old, tons per square foot.)	
Portland cement, 1 to 4	40
Rosendale cement, 1 to 3	13
Lime mortar, best	8 to 10
Best Portland cement, 1 to 2, in ¼-inch joints for bedding iron plates	70

* These loads are those allowed by the Chicago Building Ordinance.

TABLE X.*

Thickness of Walls for the Dwelling-house Class of Buildings.

This classification includes the following kinds of buildings: Apartment-houses, asylums, club-houses, dormitories, convents, hotels, dwellings, schools, hospitals, studios, laboratories, tenements, lodging-houses and parish buildings.

The total heights cannot be increased, but the intermediate heights may be varied, the various heights being measured to the nearest tier of beams.

The following numbers refer to the sections in Diagram X, reading from left to right.

No. 1. The walls above the basement. Dwelling-houses not over three stories and basement in height, not over 20 feet in width and not over 55 feet in depth shall have side and party-walls at least 8 inches thick, and front and rear walls 12 inches thick.

No. 2. Walls of dwellings over 20 feet in width and not over 40 feet in height shall be at least 12 inches thick. Walls of dwellings 26 feet in width between bearing walls, and over 40 feet in height but not over 50 feet in height, shall be at least 12 inches thick above the foundation walls. No wall shall have a 12-inch portion measuring more than 50 feet in height.

No. 3 If over 50 feet, and not over 60 feet in height, the walls shall be at least 16 inches thick in the story above the foundation walls and thence at least 12 inches thick to the top.

No. 4. If over 60 feet and not over 75 feet in height, the walls shall be at least 16 inches thick above the foundation walls to a height of 25 feet or to the nearest tier of beams and thence at least 12 inches thick to the top.

No. 5. If over 75 feet, and not over 100 feet in height, the walls shall be at least 20 inches thick above the foundation walls to a height of 40 fee, or to the nearest tier of beams; thence at least 16 inches thick to a height of 75 feet, or to the nearest tier of beams; and thence at least 12 inches thick to the top.

No. 6. If over 100 feet and not over 125 feet in height, the walls shall be at least 24 inches thick above the foundation walls to a height of 40 feet, or to the nearest tier of beams; thence at least 20 inches thick to a height of 75 feet, or to the nearest tier of beams; thence at least 16 inches thick to a heigh of 110 feet, or to the nearest tier of beams; and thence at least 12 inches thick to the top.

No. 7. If over 125 feet, and not over 150 feet in height, the walls shall be at least 28 inches thick above the foundation walls to a height of 30 feet, or to the nearest tier of beams; thence at least 24 inches thick to a height of 65 feet or to the nearest tier of beams; thence at least 20 inches thick to a height of 100 feet or to the nearest tier of beams; thence at least 16 inches thick to a height of 135 feet or to the nearest tier of beams; and thence at least 12 inches thick to the top.

*Tables X and Y, with the accompanying diagrams, were compiled by Mr. Louis A. Abramson, and are based upon the requirements of the New York City building laws.

DIAGRAM X.

WALLS FOR THE DWELLING-HOUSE CLASS OF BUILDINGS.

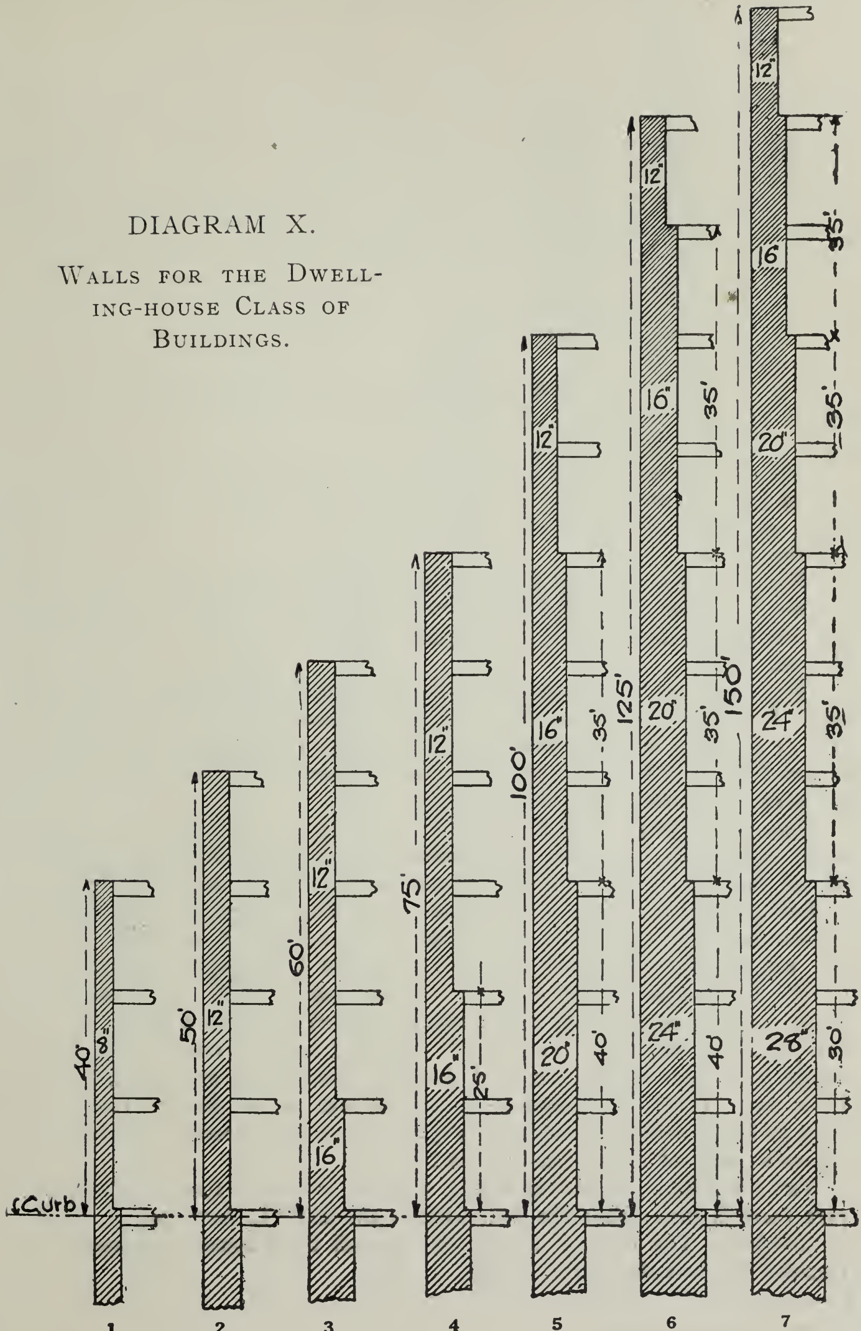

TABLE Y.*

Thickness of Walls for the Warehouse Class of Buildings.

This classification includes the following kinds of buildings: Armories, breweries, churches, cooperage shops, court-houses, factories, foundries, jails, libraries, light-houses, power-houses, machine-shops, markets, mills, museums, obervatories, office-buildings, police-stations, printing-houses, public assembly buildings, pumping buildings, railroad buildings, refrigerating houses, slaughter-houses, stables, stores, sugar refineries, theaters, warehouses and wheelwright shops.

The following numbers refer to the sections in Diagram Y, reading from left to right:

No. 1. The walls of all warehouses 25 feet or less in width between walls or bearings shall be at least 12 inches thick to a height of 40 feet above the foundation walls.

No. 2. If over 40 feet and not over 60 feet in height, the walls shall be at least 16 inches thick above the foundation walls to a height of 40 feet, or to the nearest tier of beams and thence at least 12 inches thick to the top.

No. 3. If over 60 feet and not over 75 feet in height, the walls shall be not less than 20 inches thick above the foundation walls to a height of 25 feet or to the nearest tier of beams and thence at least 16 inches thick to the top.

No. 4. If over 75 feet and not over 100 feet in height the walls shall be at least 24 inches thick above the foundation walls to a height of 40 feet, or to the nearest tier of beams; thence not less than 20 inches thick to a height of 75 feet, or to the nearest tier of beams; thence at least 16 inches thick to the top.

No. 5. If over 100 feet, and not over 125 feet in height, the walls shall be at least 28 inches thick above the foundation walls to a height of 40 feet, or to the nearest tier of beams; thence not less than 24 inches thick to a height of 75 feet or to the nearest tier of beams; thence not less than 20 inches thick to a height of 110 feet or to the nearest tier of beams; thence at least 16 inches thick to the top.

No. 6. If over 125 feet and not over 150 feet in height, the walls shall be at least 32 inches thick above the foundation walls to a height of 30 feet or to the nearest tier of beams; thence at least 28 inches thick to a height of 65 feet or to the nearest tier of beams; thence at least 24 inches thick to a height of 100 feet or to the nearest tier of beams; thence at least 20 inches thick to a height of 135 feet or to the nearest tier of beams; thence at least 16 inches thick to the top.

For walls over 150 feet in height, each additional 25 feet in height, or part thereof, next above the foundation walls shall be increased 4 inches in thickness. The uppermost 150 feet of wall shall remain the same as specified for a wall of that height.

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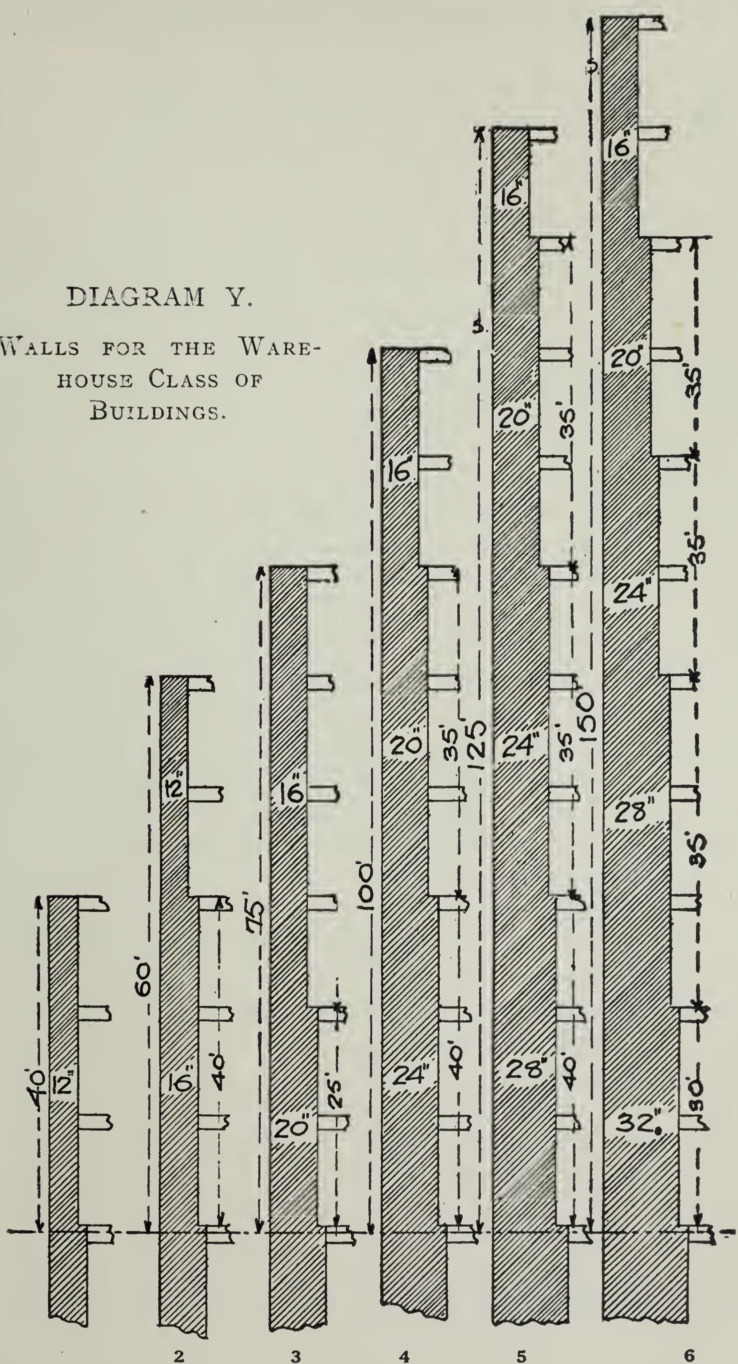
*See footnote for Table X.

DIAGRAM Y.

Walls for the Warehouse Class of Buildings.



The White System of Fire-proofing.

ON pages 518 and 519 will be found a description and sectional drawings of the system of fire-proofing of the White Fire-proof Construction Company, 1 Madison Avenue, New York City.

The system of reinforcement used by this company in its work was one of the first put on the market, and that at a time when the theory and method of reinforcing concrete were comparatively little understood. It is interesting to note that the successive steps and developments in the line of concrete reinforcement have demonstrated that the system put into use by this company at so early a date was correct in principle, and accords with the best practices of the present day.

In addition to this, it has always been the contention of the White Fire-proof Construction Company that the work covered under the head of "Fire-proof Construction" in a specification should include not only the fire-proof floor work between the steel beams, but also the fire-proofing with concrete of all columns and other structural steel members of a building, as well as all metal furring and lathing for ceilings, partitions, outside wall furring and ornamental plaster effects—*i. e.,* girders, transoms, cornices, vaulted ceilings, penetrations, etc. In a word, the claim is made that the fire-proofing contractor should follow the steel framework and the outside masonry walls by installing all the above-mentioned work, one part after the other, so as to leave the entire building ready for the plasterer to start his work.

As an illustration of one of the many instances where such a course is desirable may be mentioned a case very common in fire-proof buildings, where the hangers for the metal lath ceilings and the ornamental framework for the plaster must be attached to the steel beams before the concrete floors are installed, so as to avoid much damage by cutting and patching later on. If all the above work has been specified and contracted for under one head, no question of divided responsibility in connection with this work can arise. Numerous other instances can be quoted along the same lines.

It would seem that this method of procedure has many points in its favor, not only from the builder's standpoint, but from the standpoint of the architect also, both of whom by specifying or

contracting for all of this work as a unit will avoid all risks of duplications or omissions.

The White Fire-proof Construction Company has prepared a number of different skeleton specifications which, in conjunction with its catalogue, makes the writing of the fire-proofing part of a building specification a very simple matter for any one, insuring at the same time a thoroughly first-class and economical result. The very wide use which these specifications have attained among architects indicates that specification writers are quick to avail themselves of anything that proves of real assistance to them.

In fire-proof construction there are a number of points which very few architects take the trouble to mention specifically in their specifications, but which are of the utmost importance to the general results to be obtained. Among these may be mentioned the proper spacing of the tension rods in the concrete and the proper location of these rods in relation to the under side of the concrete slab. It is needless to say that the proper location of these rods increases the efficiency of the construction many times over one in which they are put in in an improper manner.

Another matter of the utmost importance to architects in specifying the furring and lathing is the method in which the same should be assembled. In the last few years the custom of tying together the furring bars to form the framework for the lath has come largely into use, especially on the poorer grades of work, and it is a fact that such work has occasionally been passed by architects who ordinarily demand a good quality of workmanship. A moment's thought will convince any one that the only proper and safe method of assembling furring is by bolting the various parts together, thus making a rigid frame which is practically proof against deterioration and will therefore hold the plastering together for an indefinite period. Furring which is tied up has proved to be entirely inadequate as a permanent support for plastering, and many an ornamental ceiling has been entirely ruined and the owner put to great expense within a few years of the completion of his building on this account. As the difference in cost between the methods of bolting and of tying up furring is very slight, there would not seem to be a single good argument in favor of the latter way of erecting furring. The specifications above referred to cover these points very thoroughly.

The White Fire-proof Construction Company also acts in an advisory capacity in connection with building projects which offer new and difficult problems of fire-proofing.

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Cement, Portland.

Concrete, Reinforced.

Q

R

Wall, Walls—Water.